Issue 01 | November 2015

i wonder...

Rediscovering school science

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WHY DO THINGS MOVE?

Interdisciplinary paths to exploring motion

A publication from Azim Premji University

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Rediscovering school science

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Editor's Desk

Wonder is what I felt as a child when I looked up at the village night sky and beheld the awe-inspiring sight of hundreds of winking stars. Wonder is what I felt when the chemistry teacher presented the grouping of elements in the periodic table. I feel wonderstruck even today, each time I learn a little more of the intricacies of the functioning of each organ, tissue and cell of the human body. Wonder at the natural world has paved the way for many scientific discoveries that changed the world. Wonder is an essential ingredient of scientific temperament. A teacher who evokes wonder in a classroom succeeds in capturing the imagination of students. This is the reason we chose to name this science magazine 'I wonder...'

'I wonder...' is dedicated to middle school science teachers across the country who are igniting the scientific spark in their classrooms. It brings together perspectives and experiments from many science teachers, teacher educators and researchers. We hope that it will be used as a resource by teachers, offering them a wider and deeper perspective of the topics they teach: perspectives that help them explain fundamental concepts, their evolution and their interconnections. This magazine is also for teachers to share activities, resources and insights from their own classrooms with a larger audience.

In our inaugural issue, we explore an important aspect of science that is seldom evident in school textbooks - its inter-disciplinarity. To understand any concept in its entirety, we must examine it from the perspective of many streams- physics, chemistry, biology and others and often through combining these disciplines. Hence, the theme for this issue is interdisciplinary science.

In addition, we have sections that light up many other aspects of science that help spark interest and wonder in a classroom. These include sections that throw light into the rich history of science; explore the space inside, around and far away from us; or share the latest exciting events in science. For those of you looking for resources, we have posters, experiments and introduction to some free online resources. We also have a section that looks at Nature of Science.

We hope you have as much fun reading this issue as we had putting it together. We look forward to getting a lot of feedback from our readers so that we can fine-tune the content to suit your needs. You can mail your feedback to us at iwonder.editor@azimpremjifoundation.org.

Ramgopal (RamG) Vallath
Editor

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WATER
A SURPRISING MOLECULE

Yasmin Jayathirtha

Why is our search for extra-terrestrial life forms linked to a search for water? Why does ice float in a glass of water? What makes water different from other liquids? In this article, the author uses many everyday observations of water to explore it as a topic that can be studied across classes and disciplines.

Water is the most common liquid we know and we use it without thinking too much about it, except to grumble when it spills, overflows, rain gets in… or to long for when we are thirsty, the tank runs dry or it doesn't rain.

Water plays many roles in our lives, the lives of all organisms, and the planet in general. It is studied by chemists, physicists, biologists and engineers, and research is still being done on it. This is surprising, because it is such a small molecule, such a simple formula - H2O, probably the first that any science student learns.

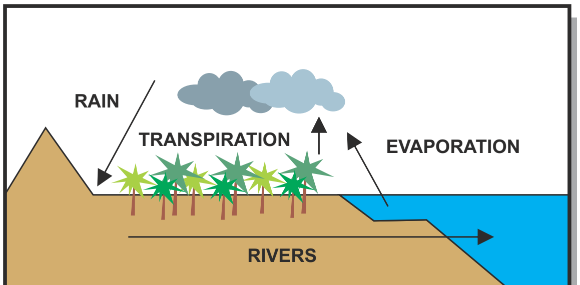
Felix Franks is a British scientist whose work is mainly on the structure and properties of water. He narrates the following anecdote: he was travelling by train to present a lecture on water at a university. He shared his compartment with another scientist who was travelling to the same place for a job interview. On hearing the title of Frank's lecture, he is supposed to have said 'I thought everybody knew the structure of water is H2O'. Franks says 'needless to say, he did not get the job.'

What are all the roles that water plays?

1. It provides an environment for living.
2. It acts as a structural material.
3. It is a very good solvent.
4. It is a transport medium, at large and small scales, for both material and energy.
5. It acts as an insulator.
6. It is a climate moderator.
7. It acts as a coolant.
8. It is a reagent.

There are probably many more uses of water; and many of the roles listed above are linked to each other. We can find numerous examples for all of the above functions of water as we observe life around us.

Let us start with looking at some functions of water that operate at larger scales: we all have some idea of the water cycle, but the sheer volume of water moved around during this process may surprise us.



The Water Cycle
Source: *http://www.teacherplus.org/lets-experiment/the-chemistry-of-water/attachment/le-fig_water*

The seas, rivers, lakes, ponds, little puddles in rocks, and trees, all provide an environment for creatures to live, all over the world, and in all climates. Many small ponds and puddles are teeming with life, very quickly after they form - it is easy to see where the mosquito larvae come from, but what about the fish and the plants - how do they get there? The eggs and the seeds lie there, dry and dehydrated till the rains come, allowing them to germinate and new organisms to grow, providing them with a space to live in- water inside and out.

Why is water essential for life? It provides a medium, in which chemicals dissolve and react; and, also, acts as a reagent to make chemical reactions happen. Can any other compound support life in the same way, not just on Earth, but elsewhere? Xenobiologists (scientists who think about extra-terrestrial life) don't seem to think so. All search for alien life seems to centre on whether water is present elsewhere in the Universe or not. On earth, water is available, and all life has evolved to use it.

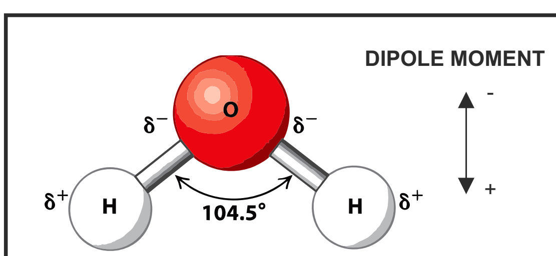
Camels are supposed to carry water in their humps to help them go long distances without drinking. What they do have in their humps is fats. The fats act both as an insulator and as a source of water. Metabolism of food gives out water and that provides part of the water that all organisms require. Metabolising 1 gram of fat gives out more than 1 gram of water. So, the camel gets both energy and water from its hump, and can go many days without eating or drinking. Some scientists have, however, argued that the hump cannot be a source of water to the camel, since taking in oxygen to metabolise the fats in the hump will cause a loss of body water through breathing.

When those of us who are terrestrial, moved from the water to land, we had to evolve ways of getting water, keeping the water in, and making sure that our offspring had water to grow. All groups of organisms solved the problem in different ways, all very marvellous to study as a biologist.

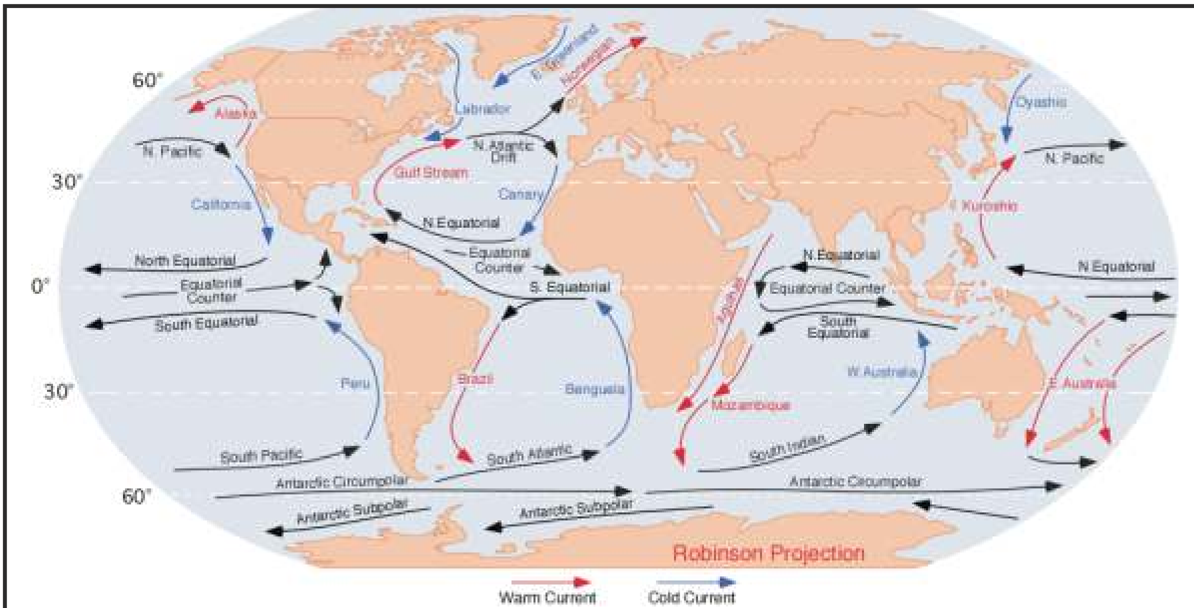
Water falls on to the Earth as rain/snow, dissolving carbon dioxide from the air, and running over land dissolving minerals (notably limestone - $CaCO_3$ through a chemical reaction); finally, either going underground, or into the seas. In the sea, marine creatures use the calcium and carbonate ions, to make shells for themselves.

As water runs over land, it erodes it - both by chemical action, and by physical weathering - shaping landscapes into valleys and gorges. Water is used for large-scale transport through canals, rivers and seas. People sail on seas, using not only seasonal winds, but also seasonal currents. Even big liners, nowadays, use ocean currents to save fuel. These water currents (Gulf stream, El Nino and others) also have important effects on climate.

What is the chemistry of this molecule that makes it so important? The formula of this molecule is H_2O, which means that it has two hydrogen atoms bonded to one oxygen atom (see image below). The atoms share electrons, but because the oxygen atom pulls more strongly on shared electrons than the hydrogen atom can, the molecule has what is called a dipole moment, i.e. one end is slightly positive, and the other, slightly negative. Now, this enables water molecules to attract each other, +ve end to –ve end. Since oxygen has electrons not involved in bonds, the



H2O molecule with dipole moment

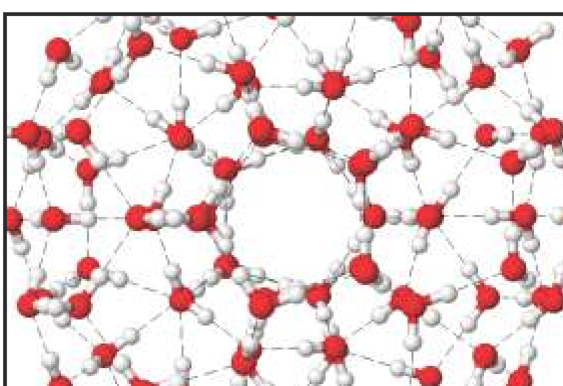


The ocean currents
Source: https://en.wikipedia.org/wiki/Ocean_current . *Public domain*

Dr. Michael Pidwirny (see http://www.physicalgeography.net) -
http://blue.utb.edu/paullgj/geog3333/lectures/physgeog.html

+ve H can interact with those electrons, and form a weak bond, called a hydrogen bond. These bonds are weak (about a tenth of the normal bond strength), but they allow water molecules to stick together. This leads to some strange (anomalous) behaviour in water, when compared to other liquids.

Water has a molecular mass of 18. Other compounds of similar masses are all gases at room temperature. That water molecules stick together with hydrogen bonds means that it takes energy to pull the molecules away from each other, and, so, water is a liquid at room temperature. Because the energy required to do this is quite large, it is liquid over a wide range of temperatures: from 0°C to 100°C.



Structure of Liquid water

Most temperature scales use the freezing and boiling points of water as their fixed points. The Celsius scale marks these as 0° and 100° respectively. The Fahrenheit scale takes the lowest temp obtained of an ice/salt mixture as 0°, and puts the boiling point of water at 212°.

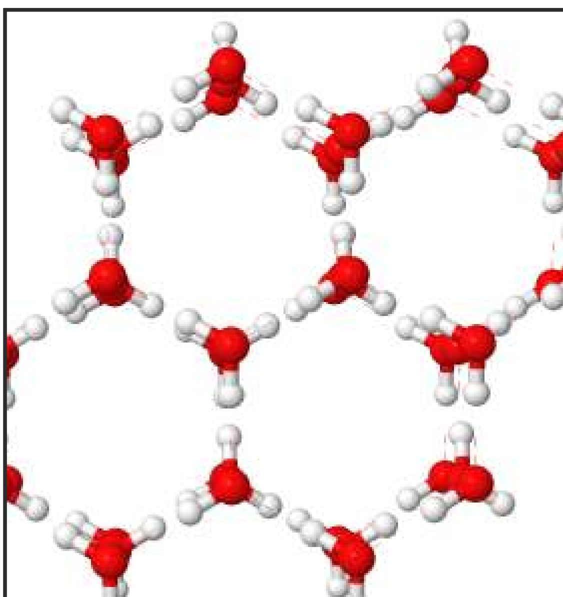
Water is the only substance we routinely see in all three states - solid (ice), liquid (water) and gas (vapour or steam).

Some of these properties of water can be explained by the strength of its hydrogen bonds. Water has a very high heat capacity i.e. it takes a lot of energy to raise the temperature of water by 1°C, and a lot of heat is given out when it cools. This means that in living organisms, heat given out by metabolic reactions is absorbed by the water in the body with a very small rise in temperature. Water bodies stabilise temperatures of adjacent landmasses, absorbing heat in summer, and releasing it in winter. Coastal cities and cities near large lakes have far more moderate temperatures than inland ones. The same explanation is true for sea breezes; the land warms up more than the sea during the day, and hot air rises, pulling in the cooler air from over the sea. On a larger scale, seasonally, the same

phenomenon is one of reasons for the monsoon patterns in India. On a much smaller scale, swimming pools feel cool on a hot day (the water has not warmed very much) and warm on a cool morning (since it has not cooled too much).

Water has large heats of fusion and vaporisation, i.e. it takes a lot of energy to convert ice at 0° C to water at 0°C and water at 100°C to steam at 100°C. Transpiration in plants and perspiration in animals help them get rid of excess metabolic energy by using it to evaporate water, and cool their bodies.

All these properties of water are explained by the strength of the hydrogen bonds, but water has other properties that are not so easily explained. When liquids are cooled they contract since the molecules that make them have less energy at lower temperatures and are, thus, closer together. This contraction continues till liquids freeze. So, usually, solids are denser than their liquids. As water cools, its density increases, till it reaches 4°C; then begins to decrease. Ice is less dense than liquid water, as is obvious when you see ice floating in your glass. This has profound implications for aquatic life in colder climates. As the weather gets colder, surface water cools down and sinks to the bottom. This process continues till the temperature reaches 4°C and, then, the cooler water stays on top, since it is less dense. When water freezes, it does so from the top, and the rest of the lake for example, stays at ~ 4°C. All the aquatic organisms in the lake can thus survive winters in relative warmth. On the other hand, the expansion when water freezes in cracks within rocks causes physical weathering.



Structure of ice

Many properties of water show this kind of behaviour - not changing continuously with temperature, but showing a minimum or maximum.

1. Heat capacity goes through a minimum at 35°C. Most liquids show a continuous rise.
2. Compressibility - Water is very difficult to compress. Unlike most liquids, water has a minimum at ~46°C. This property allows organisms (both plant and animal) to use water as a skeletal material. Plants are turgid, and wilt when they lose water. Jellyfish, earthworms, and other animals, have water as a skeleton.
3. Speed of sound in water - increases up to 74°C, and then starts to fall.

These are just a few of the properties that show that water behaves differently from most liquids. A lot of current research is focussed on explaining why this may be so.

At room temperatures, water molecules are in loose clusters, held together by hydrogen bonds and exchanging partners rather readily. As the liquid begins to cool, the clusters begin to move into more open-ended arrangements, forming four hydrogen bonds each. So, ice has a more open structure than water, and is less dense and more insulating. As ice melts, about ~ 15% of its H bonds are broken, reducing its volume. As more energy is given to this process, the temperature rises, and more hydrogen bonds are broken, increasing the density of water. But, water molecules move further apart from each other at higher temperatures, decreasing the density of the liquid. The balance of these two opposite processes gives water a maximum density at 4°C. The same interplay between open and closed hydrogen bonded structures give rise to the anomalous structure and properties of water that continue to remain a hot topic of research.

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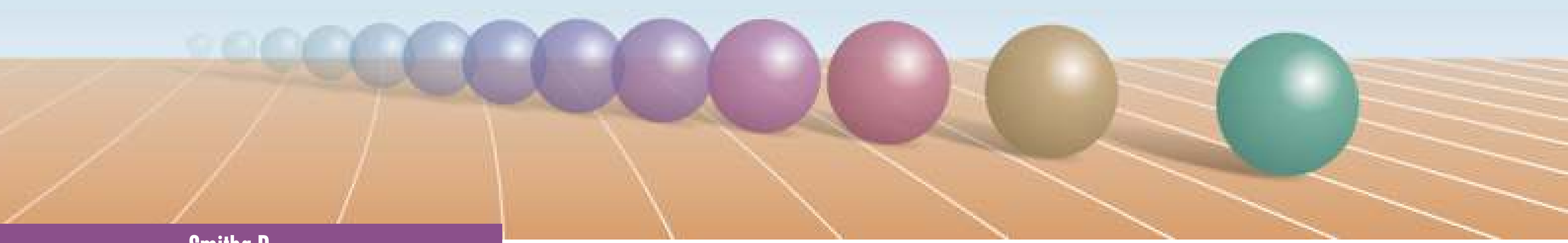
Why Do Things Move?

Interdisciplinary Paths to Exploring Motion



Smitha B.

Most human understanding of motion is relatively recent – whether it's the movement of the Earth, the expansion of the Universe, the perpetual motion of atoms or the mechanisms of movement in life forms. Integrating our understanding from various disciplines is crucial for a holistic approach to this phenomenon. This article suggests studying the causality of movement through various disciplines as a unifying theme between them.

"The world is always in movement." – V. S. Naipaul[1]

Do you remember the first time you saw a shooting star burn its way across the night sky? I still recall the awe I felt as a child in discovering its sudden bright movement, and then its abrupt disappearance. It was so briefly visible that it could have been a trick of the mind!

There are many such movements we see in nature that are magical. Whether it is the slippery motion of a snake, the soothing crash of waves on a beach, or the briskly infolding leaves of a touch-me-not, movements are fascinating.

Even things that seem to be still are moving. Plants move significantly even though they are rooted. Only their movement is so slow that it takes us weeks, months or years to detect it. The surface of our planet, mountains and glaciers, all move by inches over centuries. Even when there is no wind, the air around us is moving. We see this movement only when a beam of light falls into a dark room, lighting up dancing particles of dust. And light itself moves, although too quickly for our eyes to sense.

Since motion is such a widespread phenomenon, it is studied across subjects in our schools. Exploring this topic with middle-school children can be a rich and interesting experience. The urge to move is irrepressible in children – just ask any teacher who has tried to keep her class motionless! This craving to move can be usefully combined with students' zeal for asking questions in teaching this topic.

Some biology textbooks mention that movement is a characteristic of life. But geography, physics and chemistry tell us that oceans, galaxies, and all molecules move too! So, how is movement a trait of life alone? Actually, is **anything** in the Universe stationary? And what makes all these things move? Such questions can be common themes we use to approach the topic of movement from an interdisciplinary perspective [2].

What is movement?

"I do not define Time, Space, Place, and Motion, as being well known to all. Only I must observe that the vulgar conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices…" -- Sir Isaac Newton [3].

An early challenge in preparing an interdisciplinary curriculum is to become familiar with the language used in different

disciplines for similar concepts[4]. For instance, what is the difference between "movement" and "motion"? How about "locomotion" and "displacement"?

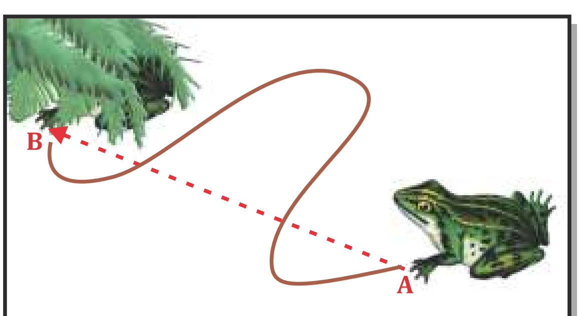
Then, there are many terms specific to each discipline that are useful to know. Some such terms in this topic would be: speed, velocity, acceleration, momentum (in physics); rotation, revolution (in geography); bone, cartilage, muscle and joint (in biology). We should also check whether the same words have varied meanings in different subjects.

So, is there a difference between "movement" and "motion"? Not really, although one of these words is used more frequently in each discipline. For example, our physics textbooks usually use the term "motion" rather than "movement". Both movement and motion refer to change in position in space over time.

> We say that the Himalayan tectonic plate **moves** because it **changes position by around two centimeters each year,** moving towards Central Asia[5].

Does "movement" mean the same thing as "locomotion" or "displacement"? No, because the last two terms have a more specific meaning than just "change in position".

In biology, "locomotion" refers to the complete relocation of an organism's body to a new position. So, all movement by an organism is not locomotion. For example, you have not undergone locomotion if you move your hand while sitting - there is a movement of the hand but no relocation of your body.



Look at this picture of a frog that moved from an exposed position at Location A to the camouflaged Location B. It moved along the path shown by the dark brown curve.

Its displacement, however, is much less, and is depicted by the dotted arrow from A to B. The frog had undergone locomotion as it moved from A to B. When it crouches or blinks its eyelids at point B, however, it moves but doesn't show any locomotion or displacement.

Displacement, on the other hand, is a term from physics. It refers to the least distance between the initial and final positions of an object. It also indicates the direction of movement. In the previous example, if the hand had moved 10cm to the right side of the body, its displacement would be 10cm towards the right.

The different kinds of movements around us

An excellent way to introduce the topic of 'movement' in the middle-school classroom is to start with exploring individual student observations. Ask students to observe and list out movements around them. Remind them to look for all kinds of movements – of animals, of things moving in the wind, the automated movement of machines, even the flow of water.

Once they've prepared their lists, ask student to mimic the movements they've observed, and demonstrate them in class. *Kinesthetic learning,* a way of learning by doing, can be used frequently in teaching this topic. As Susan Griss says, "Simply by getting students out of their seats, we begin to break the mould of "I-don't-really-want-to-be-here education". It's a crime to make students sit still while learning about movement[6].

It will be useful to end this activity by encouraging students to sort the different kinds of movements they have observed, by type. So, what are the different kinds of movements around us? The classification of movements, again, varies by discipline.

Ask a physicist, and he will drop names such as 'translational', 'periodic', 'harmonic' and 'rotational'. A biologist, on the other hand, will use nasty words such as 'nastic' and 'tropic', and, then, bombard you with 'crawl, climb, hop, glide, hover, undulate…' An earth scientist might mention 'rotations, revolutions, waves, tides and currents'. A chemist would talk of 'vibrations, Brownian motion', and so on. How do you make sense of this cacophony?

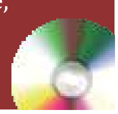
Take a deep breath, and remember that all these categories are here for our convenience. We only

need to go into as much detail as is needed for our students.

Let's start with the basic kinds of movement as defined by **Mechanics.** Mechanics, as you know, is the field of physics that deals with the motion of bodies under the action of forces. In mechanics, movement can be of four kinds.

Movement that results in a change of location is called ***translational motion***. Is there any other kind of movement, you ask? Well yes, there can be. If, for instance, a train travels from Bangalore to Delhi and then back to Bangalore, it has moved quite a bit. But there is no net change in its position. Similarly, an object that repeatedly moves between 2 positions exhibits ***oscillatory motion.*** If, on the other hand, an object spins around itself without going anywhere, it shows ***rotational motion**.* And finally, an object whose movement is unpredictable undergoes ***random motion**.*

> A caterpillar that crawls down a plant to reach the ground shows translational motion. The repetitive movement of a pendulum is an oscillatory motion. The spinning movement of a CD in a CD player is rotational motion. The movement of molecules in a gas is unpredictable, and is random motion.



Animal movements

"Flying insects and birds beat their wings up and down, swimming fishes beat their tails from side to side, and running mammals swing their legs backward and forward. In all these cases, a structure that has mass is oscillated in a fluid (either air or water), which resists its motion." – R. McNeill Alexander [7].

So far, we've looked at four kinds of movement. Isn't that enough for our classes? Well, look at the difference between saying "kangaroos hop while horses gallop" and "kangaroos and horses undergo translational motion"! Almost all animal locomotion is translational motion; when we wish to describe the movement more precisely, we use other words.

Kinds of animal locomotion depend on the medium in which movement occurs. All movement under water is ***swimming,*** although this can be further divided into categories such as ***undulation*** and ***propulsion.*** Movement in air is ***flying*** of various kinds – ***gliding, hovering*** and ***flapping.*** Movement below the ground is usually ***burrowing.*** Movement on land is the most diverse, and can be a ***walk, run, hop, climb, jump*** or ***crawl.***

All these movements result in translational motion. But are other kinds of motion observed in animals? Think of the beating of your heart – it keeps beating, but in the same place inside the chest. This is an example of oscillatory motion, where the heart moves back and forth between two positions. Now move your head from side to side. The pivot joint in your neck which allows you to move your head in this manner relies on rotational motion. Can you think of other examples of oscillation and rotation in animals?

Plant movement

"They have to fight one another, they have to compete for mates, they have to invade new territories. But the reason that we're seldom aware of these dramas is that plants of course live on a different time-scale." -- Sir David Attenborough [8].

We don't usually think of plants as moving, but they have lots of action in their lives. The ones that catch our eyes are the ***rapid plant movements**.* These movements occur within a fraction of a second or in a few seconds. Examples of such rapid movements include the Venus flytrap snapping shut on its prey, and leaf movements in the touch-me-not and the telegraph plant. The quickest known movement in plants is the catapulting of pollen from white mulberry trees – this happens at half the speed of sound [9]!

However, most plant movements are mind-numbingly slow, occurring over weeks and months. These movements take place in response to stimuli such as light, water, gravity, chemicals and the sun. The most famous of these movements is the "solar-tracking" done by sunflowers. Some other examples include the growth of primary roots towards gravity, and the bending of stem tips towards light.

These plant movements look much more interesting when captured through time-lapse photography and speeded up. Take a look at some fascinating time-lapse videos of plant

motion at this website created by Roger P. Hangarter: http://plantsinmotion.bio.indiana.edu [10].

Movements of heavenly bodies

"...Our sense of sight presents to us four satellites circling about Jupiter, like the Moon about the Earth, while the whole system travels over a mighty orbit about the Sun in the space of twelve years..." -- Galileo Galilei and Johannes Kepler [11].

We've looked at movements in living creatures which are similar to us in scale of size. Let's now look at movements at a larger scale - of planets and stars and the Universe itself.

For most of history, humans have thought that the Universe revolved around the Earth. After all, didn't the Sun rise in the east and set in the west? And didn't stars and planets move around the Earth at night? Our current, drastically altered understanding of movements in the Universe was achieved through the work of many courageous scientists who challenged authority.

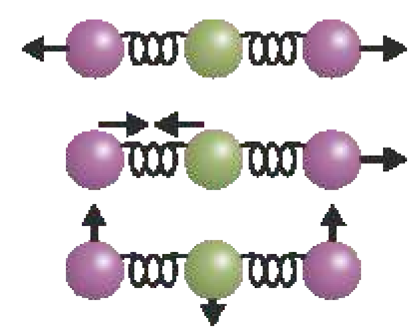
The Geocentric theory of the Universe claims that the Sun, Moon, stars and planets all circle the Earth. Nicolaus Copernicus did not publish his work that questioned this theory until just before his death, since it was considered blasphemy! Galileo Galilei was persecuted by the Church for daring to say that it was the Earth that moved around the Sun rather than vice versa. Modern science began once humans accepted that the Earth is not the centre of the Universe. Rather, the Earth rotates around itself from West to East every 24 hours – and so celestial bodies seem to move around us from East to West.

After the Greeks, Copernicus was the first to suggest that the five visible planets and Earth move around the Sun. Galileo made detailed observations using his telescope and discovered the presence of satellites around Jupiter. And Johannes Kepler proposed that the orbits of planets and satellites are not circular but elliptical. With the discovery of further planets in the solar system (Uranus, Neptune and Pluto), the movements of planets in the sky were mostly explained by Kepler's ***Laws of Planetary Motion***.

We now know that the Earth rotates around itself and revolves around the Sun. What kinds of movements are these?

By the early twentieth century, it was accepted that even the Sun is not at the centre of our galaxy. Instead, it is one of many stars on a minor arm of the Milky Way. And Edwin Hubble was able to prove that there are many thousands of such galaxies in the immense Universe. Even more interestingly, Hubble's data showed that the further a galaxy was from the Earth, the faster it was moving away. This implied that most galaxies were moving away from each other at ever-increasing speeds. And, therefore, that the Universe was expanding!

Movement of molecules



Molecules vibrate in many different patterns
Ref: http://scied.ucar.edu/molecular-vibration-modes

"For thou wilt mark here many a speck, impelled

By viewless blows, to change its little course,

And beaten backwards to return again,

Hither and thither in all directions round.

Lo, all their shifting movement is of old,

From the primeval atoms..."

– Titus Lucretius Carus [12].

From planets and galaxies, let's now move to the other end of the scale, and peer at the sub-microscopic level. We now accept readily that all matter is made up of atoms or molecules. But for centuries, atoms were just a fantastic concept, with no real evidence. However, Lucretius' quote above, made more than 2000 years ago, held the germ of proof for them!

Robert Brown, while studying pollen under his microscope, observed some particles ejected from pollen. These particles were continuously moving in water in a jittery manner as if they were alive. This random motion of particles suspended in a liquid or gas (fluid) is now known

In his philosophical poem, Lucretius described the eye-catching motion of dust particles seen in a beam of sunlight. He surmised that dust was kicked around by invisible moving atoms in the air. We now know that this motion of dust particles is actually due to thermal currents. But this motion is remarkably similar to Brownian motion which helped confirm the existence of atoms and molecules.

as Brownian motion. Decades later, Albert Einstein explained that these particles jittered due to collisions with continually moving atoms or molecules of the fluid itself. The motion of the invisible atoms was revealed by their moving the larger, visible particles!

We've just seen that molecules of a fluid are in continuous motion. What happens to the molecules of a solid? It turns out that solid molecules move too. The manner of movement of particles depends on the state of matter, however. This means, for instance, that water molecules move differently in ice, in liquid water, and in water vapour.

Particles of solids are tightly packed together in a regular arrangement. Yet, solid molecules vibrate and rotate about their fixed position. Vibration is a kind of oscillation about an equilibrium point. Despite these movements, solids are rigid due to the tight bonding between their molecules.

In liquids, particles are held together more loosely. Liquid particles are close but are also able to slide around one another freely. This is why liquids are able to take the shape of their container. Liquid particles exhibit vibration, rotation and translation.

Gas particles, too, show all these movements. But there is much more distance between gas particles than in liquids. Also, gas molecules move rapidly in all directions. This is why gases are able to fill any container that they are kept in.

Causes of movement

"What is the prime mover, the weaver who guides the flashing shuttles?" -- Edward O. Wilson[13].

There is a wide variety of movement in the world around us. Some of these are invisible to our eyes and some happen in our immediate environment. Others are at a scale so much larger than us that they are difficult to comprehend. But why and how do all these things move at all?

The answer to this question is quite complex and depends on the context where we raise it. Animals and plants move for reasons familiar to us. But why do molecules of a gas, or planets and galaxies move? Is there any common cause behind all these motions? It is a good idea to begin raising these questions in middle school for students to ponder over. And the best place to begin is with the familiar -- living creatures.

Why do animals move?

If you ask your students this question, they are likely to give you answers such as "to escape danger" and "to look for food or water". One way to further the discussion is to ask students why

While we readily comprehend movement in animals, it takes more imagination for us to grasp the concept of movement in plants. Sources for illustration (Animal): Garvie, Steve. The Great Trek. 2010. Wikimedia Commons. Web. 15 Apr. 2015. https://commons.wikimedia.org/wiki/File:The_Great_Trek.jpg. Attribution-Share Alike 2.0 Generic License: https://creativecommons.org/licenses/by-sa/2.0/deed.en. Sources for illustration (plants sprouting): Favreau, Jean-Marie. Sprouter. 2006. Wikimedia Commons. Web. 15 Apr. 2015. https://commons.wikimedia.org/wiki/File:Sprouter.png. GNU Free Documentation License, Version 1.2 or later: https://en.wikipedia.org/wiki/GNU_Free_Documentation_License)

animals migrate with changing weather. You could also describe animal movement in search of mates using the examples of nuptial flight of ants and termites.

> We can see from these that the ultimate cause of movement in animals is the need for food, shelter, mates and so on.

Next, it's useful to look at how movement is effected in animals. The immediate cause of movement in most animals is the contraction of muscles.

In vertebrates, muscles and bones act together as levers to bring about movement[14]. A lever is a simple machine used to produce a large force by exerting a smaller force. The principle of levers is used to produce efficient movements in vertebrates. Ask students how their muscles and bones might act as levers.

Another interesting fact is that most body movements are brought about by muscles working in pairs. Make students reflect on why muscles work in pairs. A clue to the answer is that any muscle can contract to bring about movement in only one direction.

Biceps and triceps are such a muscle pair – when the biceps contract, triceps relax, and vice versa. The contraction of biceps causes the elbow to bend; the contraction of triceps straightens the elbow again. So, muscles work in pairs to move body parts in both directions.

Why do plants move?

It's interesting to observe whether students realize that plants move for many of the same reasons as animals. The only difference, of course, is that there is no actual locomotion in plants. Ask students to name specific plant movements, and then, to consider why these occur.

For example, stems move towards light, and roots towards water, to help the plant prepare food through photosynthesis. The movement of the Venus flytrap is to help the plant get scarce nutrients, such as nitrogen, by trapping insects. The leaves of the touch-me-not close when touched, as a defence against predators. Flowers open and close to maximise their chances of pollination, fertilization and seed-formation.

> The ultimate cause of movement in plants is, again, the need for food, defence, reproduction and other necessities.

But how exactly do plants bring about movement? After all, they have no muscles, no bones and most importantly, no nervous system. The answer to this question involves an interesting mix of biology and chemistry. If your students are familiar with the basics of plant cell structure and some chemistry, you could study one or two examples of plant movement in some detail.

Slow movements in plants are brought about by different rates of growth of different plant parts. For example, when seedlings are placed inside a room, their stems bend towards the window, in the direction of light. This movement is due to elongation of the part of the stem away from light. This asymmetrical growth curves the stem towards light. Chemicals, known as growth hormones, bring about this elongation. Growth hormones make cell walls more elastic, and therefore, cells grow longer by accumulating water [15]. And this growth hormone is directed towards cells in the dark part of the stem by the action of other chemicals that detect light.

Rapid plant movements happen through a combination of phenomena. One such phenomenon is "acid growth" that is found in the Venus flytrap[16]. When the hairs of its leaf are touched, there is a change in electrical potential of the leaf. This change releases a flood of H^+ ions into the cell walls of the midrib. The H^+ions make the region more acidic, and dissolve parts of the cell wall. Cells, as a result, become free to expand by the accumulation of water. The outside of the leaf expands rapidly and so the trap snaps shut.

There are many such proximal causes of movement in plants. And we are still exploring these mechanisms to understand them better.

In the case of both animals and plants, we've seen that movement is caused by the need to maintain life – by locating necessities for life and through reproduction. And yet, we're not quite sure what this "life" is that seeks to perpetuate itself.

Why do planets, stars and galaxies move?

We've seen a variety of movements exhibited by celestial objects - they spin (or rotate) around

themselves, revolve around other bodies and speed away from the rest of the Universe. But why these objects move is a question that has baffled and intrigued humans for centuries. Students need to be introduced to the truly mysterious nature of the Universe. They could be encouraged to guess at reasons for these movements. They could also read up and find answers to this question on their own, before discussing these in the classroom. Here, we'll look at a brief overview of probable causes for the three kinds of movement mentioned earlier on.

The rotation of the Earth around itself creates the impression that the Sun and the stars revolve around it. This photograph captures the apparent motion of stars over 91 minutes in the night sky. Source: Lee, James Ronald. 91 Minutes of the Night Sky. 2010.Wikimedia Commons. Web. 15 Apr. 2015. https://commons.wikimedia.org/wiki/File:91_minutes_of_the_night_sky.jpg.

It's been observed that everything in the Universe spins – planets of the solar system, the sun, other stars, entire galaxies - **everything** spins [17]. And within a system – such as the Milky Way galaxy or the solar system – most objects spin in the same direction. In the solar system, all planets, except Venus and Uranus, rotate in the same direction as the Earth. This is because the spin itself seems to have developed as a result of the formation of these systems.

For instance, the solar system was formed within the Milky Way 4.5 billion years ago as a result of some force, possibly shockwaves from a nearby supernova[18]. This force caused a cloud of hydrogen gas to collapse on itself, through gravity. The different initial momentums with which Hydrogen particles moved towards each other, added up to produce a spin to the entire system. Similar phenomena that led to the formation of galaxies also causes them to rotate.

Now, why do Earth and other planets orbit the Sun? Planets are pulled towards the sun by gravitational force in the same manner as an apple falls to earth. The reason the Earth doesn't fall into the Sun is because it also has a sideways velocity at right angles to the Sun[19]. This sideways motion is a remnant from when the Earth was initially formed in the solar system. The sideways velocity is driving the Earth away from the Sun, while gravitational force is pulling it towards the Sun. These two are in perfect balance, and so the Earth neither falls in nor moves away. Instead it orbits the Sun continually.

Finally, why are galaxies in the Universe speeding away from one another? The answer to this question is the Big Bang[20]. When the movement of galaxies is traced backwards in time, they all seem to originate from a single point.

> The Big Bang theory was suggested to explain the origin of the Universe from this "singularity" – an extremely small, extremely hot, infinitely dense point. We don't know where the singularity came from, or how.

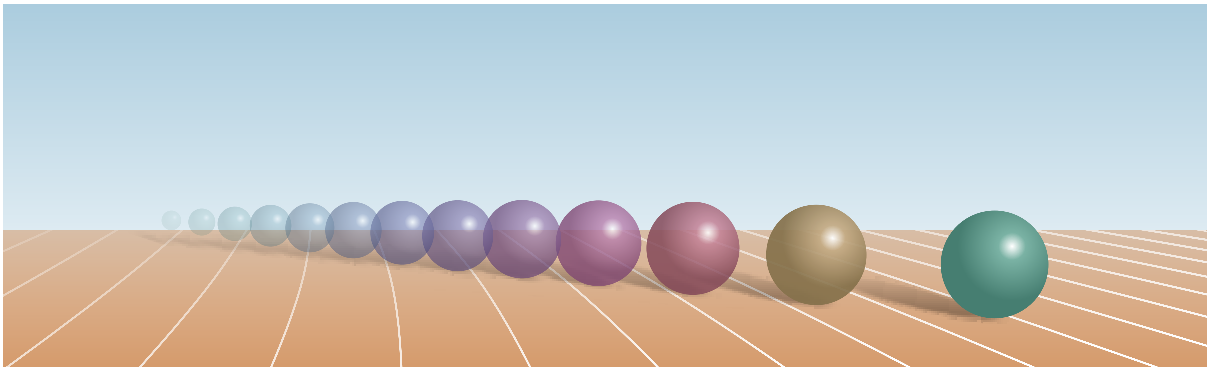
The Big Bang theory claims that 13.7 billion years ago, this singularity inflated, expanded and cooled to form the current, expanding Universe[21].

In summary, we can see that one major cause of movement of celestial bodies is gravitational force. But other causes of movement are really unknown to us – and so we guess at things such as supernovae or the Big Bang. The important thing is to impart a sense of wonder about the Universe to our students.

Why do atoms and molecules move?

Earlier, we saw how the motion of atoms and molecules varies by states of matter. But why do these particles move at all? Are there any molecules that are completely immobile?

One way to elicit guesses from students in answer to these questions is to ask them how



change in states of matter is brought about for water. Of course, we know that ice on heating changes to water and on further heating, water changes to vapour. And this phenomenon can be reversed by cooling.

The next task is to draw out students to see connections. Ask them what relation there might be between how matter changes state and how particles move in different states. They should be able to see that particles move faster on heating and slow down on cooling. The term **kinetic energy** could be introduced here as the energy of motion. The faster an object moves, the more kinetic energy it has.

Then, question students about how the **temperature** of a substance changes when heated. Let them try and define what temperature means. Of course, temperature measures the intensity of heat of an object. But the connection here is that temperature is a measure of the average kinetic energy of particles in an object. The faster the particles in the object move, the higher its temperature[22].

We've seen that particles in matter move faster when heated. So is it possible to make particles stop their movement by cooling them enough? The Kelvin temperature scale is based on this idea, since scientists theorized that the volume of a gas becomes zero at -273.15°C. This temperature of -273.15°C is considered the **absolute zero** or 0 Kelvin[23]. By definition, all molecular movement is supposed to stop completely at the absolute zero.

But there are several issues with this. There is no place in the known Universe which is at absolute zero. And it is theoretically impossible for us to create an absolute zero, although we have been able to get pretty close [24]. Finally, quantum mechanics argues that it is impossible to measure whether particles are in motion at absolute zero. And even if we were somehow able to measure motion at this temperature, particles would still have a small amount of vibration and rotation[25]! So, each and every particle in the Universe is in motion. And we don't really know why.

Conclusions

Let's repeat the question we began with – can we say that movement is a characteristic of life? After all, everything in the Universe moves. It seems more appropriate to talk of living creatures as exhibiting purposeful movement in **response to stimuli.** This is the kind of nuanced understanding that interdisciplinary studies ideally promote.

We have studied the topic of movement from multiple perspectives here for a specific reason – to try and integrate different points of view. While we learn about the world through an artificial division of disciplines, interdisciplinary curricula attempt to see the whole. Hopefully, we now have an understanding of motion that encompasses concepts from different disciplines.

Of course, the more we probe why things move, the more questions arise in our minds. In spite of all the details we study, the ultimate cause of movement in the Universe eludes us. This awareness that there is much that is unknown is an insight we must pass on to our students. For only then is an urge created to go beyond boundaries of the familiar and the known.

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The Biology of Electricity

Ramgopal (RamG) Vallath

What role does electricity play in the functioning of the human body? While electricity is mainly explored as a topic in Physics in school science, and touched upon in Chemistry, is it also important to touch upon the importance of electricity in Biology, and specifically in sustaining life? This article examines the criticality of electricity in the functioning of various processes in the human body.

Electricity is defined by the Wikipedia, as 'a form of energy resulting from the existence of charged particles (such as electrons or protons), either statically, as an accumulation of charge, or dynamically, as a current'.

In the last century, Electricity and its applications have transformed society. Today, every second of every day, unconsciously, without even realizing it, we use some gadget, or tool, or machine, powered by electricity. If we were to ask children, or even adults, to name something which is powered by this awesome force, it would be very simple for them to reel off everything from computers, to light bulbs, to machineries, to refrigerators, to mobile phones. But, I suspect, none of them would name the most complex electrically powered machine in the world. In fact, we all use this machine every single moment of our lives. Yes, I am talking about the human body.

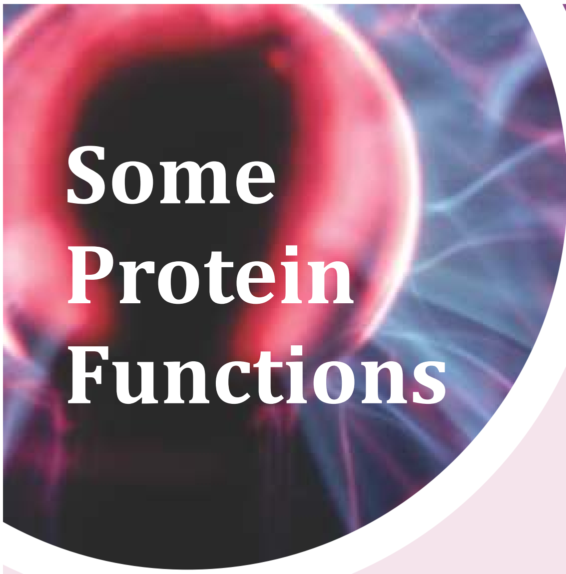
The human body, or the body of any living organism for that matter, would count under the most complex of machineries powered by the force of electricity.

Of course, I am sure that at a fundamental level, most people know that every activity in the body – from the beating of the heart, to sensing of our surroundings; from the complex cognitive functioning of the brain, to the love one feels – is powered by chemical reactions. And every chemical reaction occurs due to the complete or partial exchange of electric charges. Thus, even though most children, and even many adults, do not consciously think about it, it is apparent that electric charges play an important role in the formation of life, as it does in determining the very structure of all matter.

However, what is not as apparent is all the different ways in which electricity sustains life. In this article, I will explore some examples of this.

Proteins – cellular workhorses

One of the roles played by electricity in the body is in the functioning of one of the key building blocks of life – proteins, the workhorses in cells. There are tens of thousands of proteins in our body that perform a mindboggling number of functions at the cellular level, every second. These include…



Some Protein Functions

1. Catalysing chemical reactions in the cells

Proteins that catalyse chemical reactions are known as enzymes. Enzymes perform a variety of roles in the human body. Some enzymes, for example, catalyse the breakdown of larger food molecules into simpler components, to facilitate their diffusion through cell membranes. These include amylases that help digest carbohydrates, and pepsin that helps digest proteins. Others, like DNA Polymerase, help synthesise new strands of DNA before cell division.

2. Responding to signals

Many proteins help receive and respond to external signals. For example, Actin and Myosin, help muscle tissue, contract or relax.

3. Receiving and sending chemical signals

Certain proteins act as signalling molecules that carry information to trigger action. Insulin is a hormone that works as a signal to regulate blood sugar levels. Various receptors found in cells respond to these signals.

4. Providing structure

Many cell structures are composed of microfilaments, which in turn are composed of two proteins - Actin and Tubulin.

5. Transporting material across the cell membrane

Various channel proteins help in the transport of molecules and ions across the cell membrane by becoming selectively permeable when needed. This will be addressed in detail later on in this article.

6. Transporting respiratory gases

Certain proteins bind to respiratory gases, transporting them to different parts of the body. For example, Haemoglobin is a complex blood protein that transports oxygen from lungs to tissues.

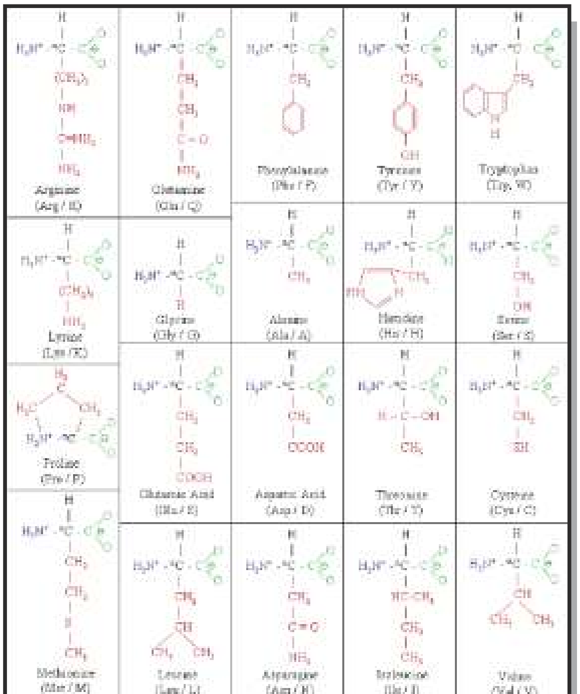
7. Defending the body against disease

Various antibodies protect the body against invading germs.

Electricity and protein shapes

Now, how exactly is electricity important in proteins? Proteins are formed by the combination of their basic building blocks - amino acids. Each of the twenty amino acids that form human proteins, have an amino group (NH2), a carboxyl group (COOH), a central carbon, which links these two groups, and a variable group (also called a side chain) that varies for each amino acid. Two amino acids combine through a covalent bond, called a peptide bond, which is formed between the amino group of one, and the carboxyl group of the other, losing a water molecule in the process. Three or more such amino acids, linked together through peptide bonds, is referred to as a polypeptide chain. It is polypeptide chains that take specific three dimensional shapes to form proteins. Each protein is able to perform specific functions, due to its specific unique shape. The

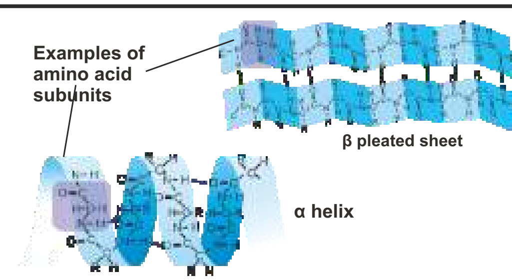
precise shape of a protein is determined by the exact sequence of amino acids in the polypeptide chains that it is composed of. In a protein that is formed by the combination of thousands of amino acids, a change in even a single amino acid, due to a mutation, may lead to a different shape, making the protein either less effective or completely ineffective in performing its designated tasks.



The Twenty Amino Acids

Proteins have primary, secondary, tertiary, and sometime quatenary structures which define their shape. The primary structure of a protein is simply the sequence of amino acids that combine to form its polypeptide chain. The secondary structure is the shape of a segment of the polypeptide chain. This is typically in the form of a helix (alpha helix) or a pleated sheet (beta sheet) formed by the folding of polypeptide chains. This secondary folding is caused by the hydrogen bonding between the electropositive hydrogen atom of one amino acid in the chain and an electronegative atom (typically oxygen) in another amino acid in the chain. This occurs due to the electrostatic attraction between these two regions of the chain. The secondary structures are further formed into tertiary structures due to various forces – hydrogen bonds; ionic bonds between basic and acidic side chains of different amino acids; disulfide bonds between sulfer atoms of different side chains; and van der Waal's forces. Finally, the whole shape is packed into a three dimensional shape by what is called hydrophobic packing. This occurs due to the fact that some amino acids have polar side chains that are hydrophilic (attracted to water) and some amino acids have non-polar side chains that are hydrophobic (repelled by water). The intracellular and extracellular fluids, where proteins reside, consist mainly of water, which is electropolar in nature. This causes proteins to fold up in such a way, that the hydrophobic sidechains move away from the fluid into the interior of the protein and the hydrophilic sidechains move to the outer side of the protein, folding the protein into well-defined three dimensional shapes.

It is, therefore, quite obvious, that electrostatic forces, in the form of hydrogen bonds, ionic bonds, and hydrophobic packing play a crucial role in determining the shapes of cellular proteins - shapes that are essential to their functioning, and ultimately to sustaining life.



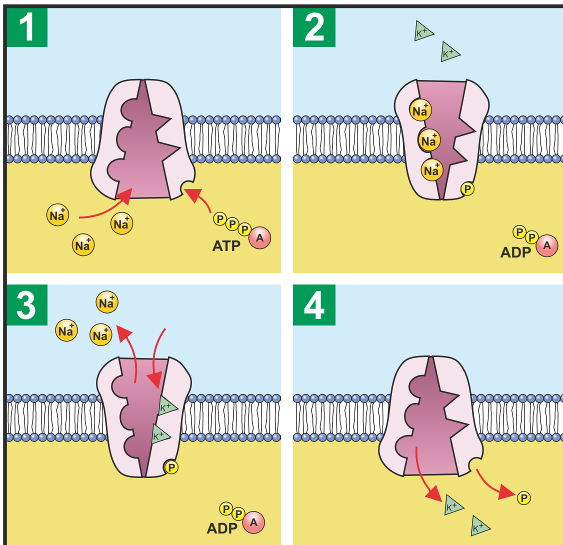
Secondary Structures- Alpha Helix and Beta Sheet

Electricity in ion channels and membrane potentials

A more direct role is played by electricity in the functioning of cells by the combined action of ion channels and membrane potentials.

Every cell in the body maintains an electric potential difference between its interior and its exterior - across the cell membrane, called resting potential. This is maintained by a difference in the concentration of specific ions inside and outside a cell. How does a cell maintain this difference? There are proteins that span the membrane, that actively pump ions across the membrane against their concentration gradient, called ion pumps. These help maintain the resting potential of the cell by constantly

pumping ions in or out of the cell. In addition, there are other membrane spanning proteins called ion channels that open when stimulated and passively allow ions to travel down their concentration gradient. These ion channels let only specific ions pass through them (the complex shapes of the proteins that make up these ion channels ensure that each type of ion channel is selectively permeable to a different ion). Sodium channels, potassium channels, calcium channels and chloride channels, are some of the main types of ion channels found in the human body. These channels, in concert with the membrane potential of a living cell, are key to the functioning of different types of cells.

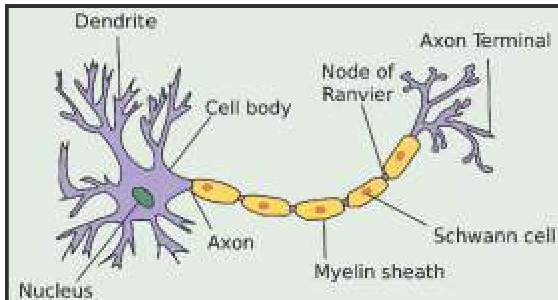


Functioning of Sodium-Potassium Pump

Let us first look at nerve cells, or neurons. When I was a middle school student, I was convinced that the human nervous system acts like the wiring of a massive machinery, with nerves carrying electrical impulses, in the form of electrons, just like a normal wire does. However, that is not the way nerves function.

Nerves do send signals in the form of electricity, but they use ions to do this; not electrons. Also, ions do not travel the entire length of the nerves carrying coded messages - they travel across the membrane of a nerve cell, causing a change in the polarity of its membrane potential – a polarity change which traverses the length of the axon, which is a long slender projection from the body of the cell that carries signals to other cells. This, in turn, causes an electric impulse to travel the length of the axon, thereby sending a signal down the nerve.

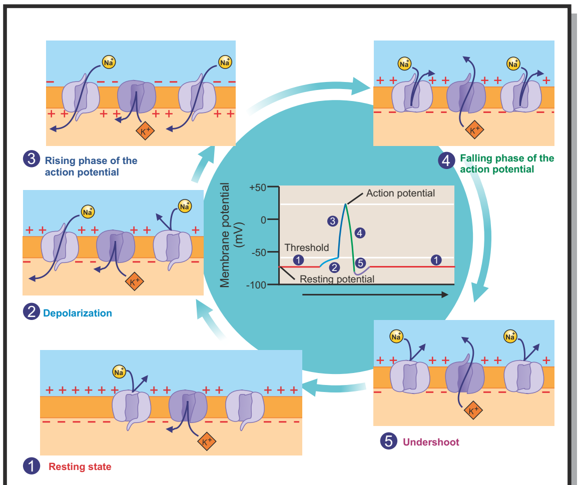
Let us see how exactly this works. In the normal state, a nerve cell maintains a potential difference of 70 millivolts (mV) between the outside of the cell and the inside of the cell - the inside being at -70mV compared to the outside – this is the resting potential of this cell. This is maintained by the imbalance of sodium and potassium ions inside and outside the cell. While the inside of the cell has an excess of potassium ions (K+) compared to the outside, the outside of the cell has an excess of sodium ions (Na+) compared to the inside. The degree of excess of Na+ outside is far higher than that of K+ inside, and, hence the negative potential.



A Typical Neuron
Source: *https://commons.wikimedia.org/wiki/File:Neuron.svg* Creative Commons Attribution-Share Alike 3.0 Unported

A dendrite is a short branched extension of a neuron. The neuron receives impulses from other neurons through the many dendrites it has around its cell body, or soma. Dendrites receive signals, in the form of neurotransmitters (certain chemicals), from other neurons or from sensory cells (special cells in the sense organs that convert external information such as colour, sound etc. into electrochemical signals). These neurotransmitters cause a specific type of membrane spanning ion channel called ligand-gated channel to open up. This causes Na+ ions to flow into the cell due to their concentration gradient and K+ to flow out of the cell along their concentration gradient. Since the gradient of Na+ is higher, and it is flowing down the potential gradient, the inflow of Na+ into cells is higher as compared to the outflow of K+. This net influx of positive ions into nerve cells, causes the membrane potential to drop - in other words, the membrane gets depolarized. Once the main cell body or soma depolarizes enough to reach -55mV from -70mV, it triggers the sodium ion channels, which are voltage gated – they open their gate when the cell potential reaches a threshold at -55mv. The voltage gated sodium channels on the axons closest to the soma open first, since they

reach the threshold potential of -55mV first. Once they open, there is a huge influx of sodium ions, completely depolarizing that region all the way to +30mV. This spike, called the action potential, travels down the axon rapidly since one channel opening up causes the next channel to reach threshold potential and hence open in its turn, triggering the next in turn, in a domino effect. After a very short burst of inflow of Na+ ions, these channels get inactivated, causing the potential to peak at +30mV.



Action Potential and Ion Channels

There are also potassium ion channels that open up when the threshold potential is reached, but this happens more gradually. Once they start opening up (again, one after the other, traversing the length of the axon), the potassium ions rush out, repolarizing that region of the axon. In this way, a spike of voltage traverses down the axon, which goes back to its resting potential.

The role of ion channels does not end with the transmission of signals within the neuron. Once the action potential reaches the end of the axon, it causes voltage gated calcium channels in the membrane to open at the synapses (a synapse is a structure at the tip of the axon that is used for passing on the signal to another cell), releasing a flood of calcium ions into the cell. These calcium ions, in turn, cause synaptic vesicles filled with the neurotransmitters (a vesicle is a small sac filled with the respective chemical) to fuse with the cell membrane, thereby releasing its contents into the synaptic gap (the minute gap between the synapse of a cell and the receptor of a target cell). The neurotransmitters diffuse across the synaptic gap, and bind to a receptor, either on another neuronal membrane, thereby transmitting the signal further; or on the membrane of a non-neuronal cell, such as a muscle cell.

Not all synapses are chemically operated through neurotransmitters. There are some synapses that are electrical. In these synapses, also called gap junctions, two neurons are connected via ion channels known as connexons. These direct connections allow action potentials to travel from one neuron to another, much faster than in the case of chemical synapses. Thus, electrical synapses are found in neurons that trigger extremely fast reflex actions, or where the synchronization of a large number of cells is required.

In muscle cells, for example, the neuro-transmitter acetylcholine, released through vesicles from a synapse, is what triggers an acetylcholine receptor (another protein perfectly shaped to bind to the transmitter) on the muscle fiber membrane, opening an ion channel in the receptor, and allowing sodium ions to flood in. This in turn triggers an electrical impulse in the muscle, resulting in a motor action.

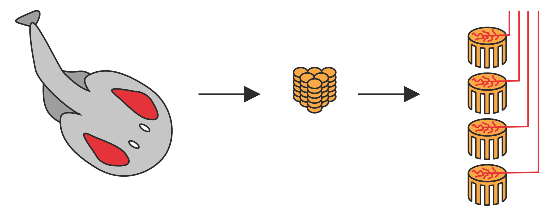
How exactly does an action potential cause a muscle fiber to contract? The answer lies in more ion channels.

Electrical impulses cause calcium channels called ryanodine receptors to open. These channels do not connect to the outside of the cell, but to a membrane bound intracellular store of calcium ions, called the sarcoplasmic reticulum. Once the ryanodine channels open, calcium ions flood the interior of the muscle fiber, causing them to contract. When the calcium ions are pumped back into this storehouse, the muscle relaxes.

What an intricate and complex electrically operated motor!!

Eels -the natural electricity generators

In some creatures, evolution has modified muscle fibres that have lost the ability to contract, into being able to perform other roles. One example of this can be seen in the electric eel, that has developed a highly effective electric shock generator, using modified muscle fibers. This creature can produce a shock of over 500 Volts and a current of about one ampere - that is half a kilowatt of power. It can even kill a human. The electric ray also produces electricity in a similar fashion.



Electroplaques in Electric Rays

Electric eels can grow as much as two to two and a half metres in length. About four-fifths of their bodies are devoted to the biological equivalent of battery packs. Each such pack consists of around 70 long columns of thin plate-like modified muscle cells, called electro-plaques, on either side. Each column has about 5000-10000 such cells stacked up together.

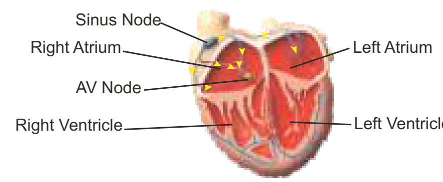
One side of each of these cells are connected to nerve ends. Normally, there is no voltage difference between the two sides of a cell. When the fish activates its weapon, it sets off an impulse down the nerve of each cell. This activates a muscle action potential on each electro-plaque, but only on the side connected to the nerves. This, in turn, produces a voltage difference across the two sides of the cell of about 150mV. Since this happens in all cells simultaneously, and since the cells in each column act in series, the combined voltage in the eel's body builds up to 500 Volts. Of course, if the weapon is used continuously, the sodium ions which flood into the cell do not have time to get pumped out. This leads to a continuous drop in the action potential, and, consequently, the voltage, till finally the battery gets completely discharged.

The electrically engineered heartbeat

The heart is another extremely precise and robust electricity powered machine – it beats around 100,000 times a day and never stops as long as it is alive. It is powered by electricity in the form of an action potential, which is generated in the pacemaker cells, in the wall of the right atrium.

Blood enters the heart via the atria – the upper chambers. These, then contract to force the blood into the the larger lower chambers of the heart, called the ventricles. About half a second later, the ventricles, in turn, contract to pump the blood out – the left ventricle to the body; and the right ventricle to the lungs.

For the proper and efficient functioning of the heart, it is critical that the rhythms of these contractions are maintained, and also that the left and right sides contract together, with all the contractile cells contracting in unison.



Heart – Pacemaker Cells and Electrical Impulses

The pacemaker cells that drive the rhythm of the heart are collectively referred to as the sino-atrial node. The electrical impulse that stimulates the heart is initiated by sodium ion channels. This reverses the membrane potential, and that, in turn, opens calcium ion channels within these cells, flooding the cells with calcium ions from outside. These ions, in turn, open other calcium channels that cause a larger number of calcium ions to be released from intracellular stores. The calcium ions interact with contractile proteins and make the heart muscles contract. The advantage of having calcium channels here, is that, unlike sodium channels, they remain active as long as the membrane potential is positive. Since, the action potential is close to half a second, calcium channels help ensure that the resulting muscle contraction is longer. Now, potassium channels open, repolarizing the cell, and causing the calcium channels to close. These potassium channels open even more slowly than the potassium channels of nerve cells, giving the action potential in the heart the time it requires to act.

Each impulse travels from the pacemaker cells to atrio-ventricular node cells (located between atria and ventricles), and then to cells all around the ventricles. This ensures that the atria contract first, and then the ventricles, leading to the all too familiar 'lub-dub' rhythm of the heart.

As you can see, the heart is a precisely engineered, timer-controlled, intricate and robust automatic electric pump.

Each one of our senses perceives the world through the activation of action potential and ion channels. In the retina, it is a complex cascade of sodium and calcium ion channels that causes this. In the ears, it is the mechanical movement of the sensory hair cells in the cochlea that pull open the ion channels that cause action potential. The taste buds have their own ion channels that generate action potential when the five basic tastes – sweet, salt, sour, bitter and umami are detected. In the nose, we have about 350 different types of

receptors, and depending on the molecule being smelled, many of these are activated, giving rise to thousands of combinations of activated cells, each combination resulting in the sense of a different smell, enabling us to have a very fine sense of smell. This happens through the binding of molecules to olfactory cell receptors, opening up specific ion channels that trigger action potentials in the olfactory neurons. The skin also has mechanically sensitive ion channels that trigger action potential when touched.

The electrically operated central processing unit – the brain

The brain, where ultimately all these sensory signals go, is the most complex electrochemically activated organ of all. It has more than a billion nerve cells, and each of them is connected to many thousands of others, giving rise to trillions of connections.

Different parts of the brain are dedicated to controlling different functions. How do we know this? We have managed to gain substantial insights into the functioning of the brain, by tracking the electrical activity in the brain as a whole, as well as in its different parts. There are various brain scanning methods which are used to measure and record electrical activity in the brain, directly or indirectly. Electro-encephalogram or EEG is one such. An EEG records brain waves by capturing information on the electrical activity in the brain. Since an EEG gives the collective activity of every neuron in the brain, its use is limited. fMRI or functional magnetic resonance imaging is far more effective in identifying regions of the brain responsible for different activities and functions. This method measures the blood flow in different regions, which is an indicator of electrical activity. By mapping the activity of different parts of the brain while subjects are asked different questions or made to do different activities such as sleeping, talking, listening, using ones limbs, looking at different pictures etc., scientists have been able to identify the regions responsible for various actions, thoughts and emotions.

I will not go deeper into the functioning of the brain, because that would require a book by itself. Suffice it to say, we are still at a nascent stage of understanding the complex functioning of the brain.

Defining the shape and growth of the body and its organs

Last but not least, I would like to touch upon some of the latest research happening in the field of bio-electricity. Recent studies seem to indicate that manipulating the resting potential of a group of cells can trigger growth. Scientists have grown new organs and limbs in tadpoles and frogs by manipulating the cell potentials of groups of mature cells. It seems possible that the pattern of cell potentials is what signals the three dimensional pattern of growth for organs or limbs, and ensures that organs grow to appropriate sizes and shapes. This has huge implications for regenerative medicine, since one could potentially regrow amputated body parts just by manipulating the electric potential of cells at the stump. The cell potential can be manipulated by genetically engineering new ion channels that change the balance of ions within and outside the cell.

Conclusion

Our understanding of the role of electricity in the human body and in biology as a whole is exploding as we are gaining fresh understanding in the field of bioelectricity every day. I am sure we cannot be faulted for calling the human body the most complex electrically powered machine in the world.

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CHEMICAL FERTILISERS:

CONNECTING CHEMISTRY LABS TO PLANT LIFE

Jaya Ayyer

Growing sufficient quantities of the various crops needed to feed an ever-increasing population is a challenge faced by many countries - particularly, developing and under-developed countries. The availability of fertile land, suitable climatic conditions, and good agricultural practices; combined with a variety of inputs such as high yielding seeds, fertilizers, pest control agents, irrigation etc., play vital roles in this respect. This article aims to give readers an introduction to chemical fertilisers, one of the most important external inputs in food production.

Humans and other animals depend, directly or indirectly, upon plants to meet all their nutritional requirements. These nutritional requirements include not just carbohydrates, proteins, and vitamins, but also a variety of minerals, including phosphorous, potassium, iron, magnesium etc. Plants, too, have similar nutritional requirements. The carbohydrate (carbon, hydrogen and oxygen) needs of plants are met through light, air and water, through the process of photosynthesis. But, in addition to carbohydrates, plants also need elements like nitrogen (N) and sulphur (S) to produce amino acids; phosphorous (P) to synthesise nucleic acids; potassium (K) for ion transport and enzyme function, etc. These elements are absorbed by plants from the soil that they grow on.

Fertile soils are rich in these essential nutrients, allowing healthy growth of plants. However, farming of food crops often involves many successive cycles of large scale growth of plants in the same soil, without allowing the soil to regenerate. Over time, this leads to depletion of all the essential nutrients that the food crops seek for their growth.

Fertilisers are all those substances that can be used to add nutrients to soil, improving soil fertility, and increasing crop growth and yields. Fertilisers fall into two broad categories. Natural or organic fertilisers include peat, animal waste, composted wastes of plants, household waste, sewage sludge, bio-fertilisers etc. Chemical fertilisers are synthetically produced, and include chemicals such as urea, calcium ammonium nitrate, ammonium sulphate etc.

This article focusses on chemical fertilisers, providing insights into different aspects of this topic, generally unavailable in textbooks.

Nutrient needs of plants and their supply

For plants to grow and thrive, a number of chemical elements are needed. These can be classified as:

a. Macro or Major Nutrient elements – Nitrogen (N), Phosphorous (P) and Potassium (K)

b. Secondary Nutrients – Calcium, Magnesium and Sulphur

c. Micronutrients – Iron, Manganese, Zinc, and Copper, along with a number of other elements like Boron and Molybdenum at trace levels.

How are these supplied to the plants so that they can be absorbed?

The above elements have to be supplied in a chemical form to the soil (though some are sprayed on the leaves). They have to be water soluble, or must dissolve slowly over a period of time. The dissolved salts (in their ionic form) are absorbed by the roots' membranes, through osmosis. The microbial system of the soil plays an important part in converting some of the applied fertilisers into absorbable forms through enzymatic processes. Microbes also fix some of the excess nutrients in the soil. Hence, effective absorption of chemical fertilisers by plants depends on the microbial activity and water content of the soil in which they grow.

Chemical fertilisers can be produced in single nutrient or multi-nutrient chemicals forms. Single nutrient fertilisers are called 'Straight Fertilisers', and multi-nutrient ones are called 'Complex Fertilisers'. Except urea, most fertilisers are multi-nutrient ones. This is because fertilisers are inorganic water soluble chemicals, which have cations and anions, each contributing a nutrient.

Complex fertilisers contain two or more nutrients, and their composition is expressed in the order N-P-K. The N content is given as % Nitrogen (N) by weight (wt.), Phosphorus (P) content is expressed as P_2O_5 by wt. and potassium (K) content as K_2O by wt. in the dry form of the fertiliser. Both P_2O_5 and K_2O are conceptual representations by convention; they are not present in these chemical forms. The Sulphur content, as S, is also mentioned in N-P-K-S complex fertilisers.

We will now take a look at chemical fertilisers available in Indian markets.

Nitrogenous fertilisers

i. Urea: The most well-known and popular fertiliser in this category is **Urea.** This is a water soluble organic chemical, manufactured from ammonia (NH_3) and carbon dioxide (CO_2) through a high pressure and temperature process. The chemical formula of urea is NH_2-CO-NH_2. Urea contains about 46% nitrogen by weight.

Very large scale production of urea from ammonia (made through the Haber Bosch Process from N and H) and CO_2, has made it possible for farmers to obtain this most common nitrogenous fertiliser at low costs (further subsidised by Government in India). Urea is obtained as prills, through a process known as prilling, in which the molten urea is sprayed from a very tall tower down and as the droplets fall, they get solidified. Urea is completely water soluble, but is not directly absorbed by the plants. It is hydrolysed by an enzyme called Urease in soil microbes to ammonium and carbonate ions. Ammonium is absorbed by plants through osmosis.

Prill Tower

One may ask why ammonia cannot be supplied directly to the plants. It can be supplied, and in countries like the US, this is accomplished through pipelines that transport ammonia directly to farms. However, in its pure form at

room temperature, ammonia is a highly pungent and toxic gas. To avoid any harmful effects, ammonia is converted to urea, an easily transportable, water soluble and easily-applicable form for farmers.

Fig. 1. Urea Prills

ii. Calcium Ammonium Nitrate (CAN): This is a mixture of ammonium nitrate and calcium carbonate, granulated together to get a total nitrogen content of about 25% by weight, of which 12.5% is ammoniacal nitrogen (NH_4 form) and the other 12.5% is nitrate nitrogen (NO_3 form). As this contains the additional nutrient calcium, it is beneficial for crops, although its total nitrogen content is less than in urea.

iii. Ammonium Sulphate: This is often obtained as a by-product, and contains 20.6% N in ammoniacal form. As it also contains Sulphur (23% by wt.), a very important plant nutrient, ammonium sulphate is a good fertiliser for a number of crops. Being 100% water soluble, this is useful for drip irrigation, where the fertiliser solution is directly applied as a dilute solution to the plant root system through pipes; and sprinkler irrigation, where the solution is sprayed on the plant.

Phosphatic fertilisers

Phosphatic fertilisers contain phosphorous (represented as P_2O_5) as the major nutrient.

Phosphorous is naturally obtained through rock phosphate, which is a mineral rich in phosphorous, and mainly contains Calcium phosphate. This is the primary source of all phosphatic fertilisers. Rock phosphate is digested with mineral acids to get phosphoric acid, along with the calcium salt of the mineral acid. For example, reaction of rock phosphate with sulphuric acid gives phosphoric acid and calcium sulphate, known as phospho-gypsum, a by-product. The phosphoric acid is neutralised with ammonia and granulated to get Diammonium Phosphate (DAP), a very popular P fertiliser.

Fig 2. Rock Phosphate after coarse grinding and sizing

The reaction of rock phosphate with nitric acid generates phosphoric acid with calcium nitrate. The phosphoric acid - calcium nitrate mixture is neutralised with ammonia and granulated to get Ammonium Nitrophosphate (ANP) fertiliser.

The process involves acidifying phosphate rock with nitric acid to produce a mixture of phosphoric acid and calcium nitrate.

$Ca_3(PO_4)_2 + 6\ HNO_3 + 12\ H_2O \rightarrow 2H_3PO_4 + 3\ Ca(NO_3)_2 + 12\ H_2O$

The mixture is cooled to below 0°C, where the calcium nitrate crystallises, and can be separated from the phosphoric acid.

$2\ H_3PO_4 + 3\ Ca(NO_3)_2 + 12\ H_2O \rightarrow 2H_3PO_4 + 3\ Ca(NO_3)_2{\cdot}4H_2O$

The resulting calcium nitrate can be used as nitrogen fertiliser. When used in a reaction with ammonium carbonate, it results in the production of ammonium nitrate, and calcium carbonate - a by-product. The fertiliser calcium ammonium nitrate (CAN) is produced by granulating a mixture of ammonium nitrate and calcium carbonate. The filtrate is composed mainly of phosphoric acid with some nitric acid and residual calcium nitrate, and this is neutralized with ammonia to produce Ammonium Nitrophosphate (ANP).

$Ca(NO_3)_2 + 4\ H_3PO_4 + 8\ NH_3 \rightarrow CaHPO_4 + 2\ NH_4NO_3 + 3(NH_4)2HPO_4$

Major Phosphatic Fertilisers are:

1. Single Superphosphate
2. Triple Superphosphate

3. Monoammonium Phosphate, MAP (11-52-0)
4. Diammonium Phosphate, DAP (18-46-0)
5. Ammonium Nitrophosphate, ANP (20-20-0)

Potassium fertilisers

The third most important plant nutrient is potassium (K). This is supplied as Potassium Chloride (Muriate of Potash, MOP), or as Potassium Sulphate. MOP is cheaper in value, and is extensively used by farmers as the K fertiliser. It is used as such, or in combination with N and P as complex fertilisers.

Complex fertilisers

These contain more than one major nutrient and are denoted as N-P-K-S. Some of the phosphatic fertilisers mentioned above come under this category as they contain N also. N-P-K complex fertilisers are extensively used by farmers. These incorporate MOP (KCl) or potassium sulphate, to get the K content.

Liquid fertilisers and water soluble fertilisers

Liquid fertilisers like Urea Ammonium Nitrate, and 100% water soluble fertilisers with multiple nutrients, have been approved by Government of India for manufacture and sale. These are used in drip irrigation and spray application. Many companies have been producing and marketing these. However, these are mainly used in horticulture and high-value crop production, due to their relatively high costs.

Micronutrient fertilisers

Although plants do not need micronutrients in large quantities like N,P,K etc., these are essential for healthy growth and production of crops by the plants. These are provided in the form of water soluble chemical salts, such as Zinc Sulphate, Manganese Sulphate, Copper Sulphate, Borax, Ferrous Sulphate, Magnesium Sulphate and Ammonium Molybdate. Chelated (EDTA) salts are added to enable easy absorption by plants.

Controlled release fertilisers

To prevent losses of fertilisers through leaching and other mechanisms, as well as to minimise multiple applications, several controlled release fertilisers have been developed. To regulate the release of nutrients slowly and over a period of time, highly water soluble fertilisers are coated with a layer of water insoluble, but soil friendly materials.

i. Sulphur coated urea (molten sulphur is coated on urea granules), SCU, was developed by International Fertiliser Development Corporation (IFDC), USA.

ii. Phospho-gypsum coated urea (GCU) was developed by the research team at Gujarat Narmada Valley Fertilisers Company in Gujarat.

iii. Urea Supergranules (USG) is another controlled-release urea fertiliser used in social forestry. Such controlled release fertilisers have shown improved nutrient use efficiency (NUE) during agronomic trials. However, their commercial use is limited, due to their high costs and low availability.

Fertiliser production in India

As per the data published by Ministry of Chemicals & Fertilisers, the following are the quantity of production of major fertilisers in India.[1]

As the indigenous production of fertilisers is not sufficient to meet the country's requirements, additional quantities are imported.

Table 1: Production of Major Fertilisers in India (Qty. in Lakh MT)

Fertiliser / Year	2006-07	2007-08	2008-09	2009-10
Urea	203.1	198.6	199.2	211.3
DAP	48.52	42.12	29.93	42.47
Complex Fertilisers	74.28	58.72	67.99	80.38

Quality and specifications of chemical fertilisers[2]

Both the specifications and quality of the chemical fertilisers sold in Indian markets are strictly controlled by Government of India. The composition, detailed specifications and the analysis procedures for each component are specified under Fertiliser (Control) Order 1985. This order is revised periodically to incorporate any changes needed, new additions to the list etc. Manufacturers have to adhere to these without any deviation. Spot quality checks are done by Government agencies in the market, and legal actions are taken against the manufacturer if the specified quality is not met. In addition to nutrient content; moisture content, size, and water solubility etc. are also strictly specified and enforced.

Administered prices of fertilisers

To ensure adequate availability of fertilisers throughout the country at affordable prices to farmers, the Indian government (Department of Fertilisers) has formulated the Fertiliser Pricing Policy. According to this policy, the selling price of major fertilisers is fixed by the government, and revised at regular intervals. The difference between costs of production (plus adequate profits) and the selling price is compensated to the manufacturing companies using certain complex formulae. This current practice of reimbursing fertiliser manufacturing companies, is called fertiliser subsidy. This mechanism is being critically examined for replacement with other methods, like direct cash subsidy to the farmers.

Application of Chemical Fertilisers[3]

Most natural fertilisers are applied directly to the soil or root system of the plants, as these are also soil conditioners. However, chemical fertilisers can be applied in multiple ways, depending on the type of crop, water availability, absorption pattern etc. Some of these application modes are mentioned here:

A. Solid chemical fertilisers

- Basal Application: A fertiliser is directly applied to the soil, and spread throughout the cropping area before sowing seeds, and periodically during crop growth. Nutrient losses are high in this case, as the solid can easily move away from the root system. To compensate for this, often, higher than required quantities are applied. Highly soluble fertilisers like urea can get leached away too. Ammonia, formed by hydrolysis of urea, also evaporates into the atmosphere.
- Application near the root system, on the surface or deeper into the soil: This is a better method as compared to basal application. However, it is more labour intensive. Use of seed-cum-fertiliser drills is beneficial for this.
- Placement in bands near rows of plants.

B. Liquid Fertilisers, Water Soluble fertilisers and Micronutrient Solutions

- Foliar application: A dilute solution of the fertiliser in water is sprayed on the plants. Nutrients are absorbed directly, by leaves.
- Through irrigation water: Water soluble fertilisers are applied through water channels.

Advantages and disadvantages of use of chemical fertilisers

For a country like India with a population of 1.3 billion people, production of sufficient quantities of food is a major challenge. From a famine affected country in the 1960's, we have managed to come close to becoming self-sufficient in food grains today, through the concerted efforts of scientists, farmers and successive governments. This has largely been possible through the use of high yielding varieties of seeds, irrigation, the use of chemical fertilisers and other agrochemicals, like insecticides, pesticides etc. Therefore, the role of chemical fertilisers cannot be undermined in achieving our current food security.

However, the indiscriminate use of chemical fertilisers can have many negative effects on the soil system, as well as on the larger environment. A balanced supply of all nutrients needed for each crop (this varies from crop to crop), along with micronutrients and soil conditioners, can ensure sustained agricultural conditions for a long time. Any imbalance in nutrient use, when coupled with the use of high yield seeds, depletes the soil of naturally occurring minerals, and over time, the soil becomes infertile.

Another important drawback of high doses of chemical fertilisers is their effects on the

environment. Water soluble chemicals used as fertiliser leach away from the soil and contaminate both ground as well as surface water. High phosphate and nitrate levels in water lead to eutrophication. When excessive nutrients reach rivers and lakes, algae and other such aquatic plants use them to grow on the water surface. This increased plant growth uses up all the dissolved oxygen in water, in addition to acting as a physical barrier to atmospheric oxygen. In the absence of oxygen, all the aquatic life in the water, but below its surface (including fish and other organisms), start dying.

Fig. 3: Eutrophication due to high nutrient content in water *Photo: Alexandr Trubetskoy*

However, as natural/organic fertilisers alone cannot yield the quantity of food needed to make food available to more than a billion people of the country, only the judicious use of chemical fertilisers, along with naturally available soil conditioners can ensure long term food security.

Conclusion

After seeds, chemical fertilisers are some of the most important inputs in the agricultural sector today, especially in achieving the high yields of crop outputs needed to ensure our food security. Depending on the specific nutrient needs of their crops, a variety of fertilisers are used by farmers. Chemical fertilisers are produced by many small and large manufacturers, within the country. Some amounts of these fertilisers are also imported every year. This industry is closely monitored and controlled by the Government of India to ensure availability of fertilisers at affordable prices to farmers. The judicious use of chemical fertilisers, along with other natural fertilisers and soil conditioners, can ensure sustained agricultural production, as well as continued and adequate availability of food for all.

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THE WORLD OF COLOUR

N.S.Sundaresan

The phenomenon of colour is explained fragmentarily in chemistry, biology and physics in schools. In this article, a case is made for teaching colour as a separate interdisciplinary unit in the middle school.

Colour is a universal phenomenon. Everyone, from a child to an adult, has some idea about colour. In almost every language, there are words for red, green, blue, yellow and many shades of colours in between. It is such an important topic that scientists from the different disciplines of chemistry, biology and physics, have studied its various aspects and applications. Colour has also been the subject of intense study by artists and poets. The former have studied the technique of creating different shades in their paintings; and, the latter have painted word pictures of colour for us. There are many examples of the important role colour plays in our everyday lives: red is used in traffic lights and in danger indication; big shops have colour codes for their merchandise; schools have coloured uniforms; football teams have different colours to distinguish them from each other; and national flags have colours. We use rangoli colour patterns on festival days to decorate the front of the house. The Indian festival of Holi is a festival that celebrates colours.

In the school science curriculum, however, the concept of colour is brought in piece-meal, at various stages. Every year, either in physics or in chemistry or in biology, it finds a mention, but never at the same time. Thus the student gets only a fragmented idea of the topic. They associate certain aspects with only physics and certain aspects only with chemistry, without realizing that the phenomenon is the same.

The purpose of this article is to draw the attention of my teacher colleagues and the odd syllabus maker who may read this article, to the possibility of including the concept of colour as an interdisciplinary topic in the science curriculum. It can be introduced in the middle school level before an introduction to topics like light, photosynthesis, chemical reactions etc. It is also suggested that the unit should be taught by one science teacher. Later in this article, an outline form for the contents of such a unit is given.

With this background, let us examine how colour is introduced in biology, chemistry and physics in the current school curriculum.

Colour in school science curricula

In chemistry, we introduce colour first through the physical properties of substances e.g. sulphur is a yellow coloured solid, copper sulphate is

blue. We also show how solutions on mixing give a solid precipitate, which is coloured, and can be used to identify substances.

In biology, photosynthesis is discussed quite early, but without mentioning colour in light, and its absorption.

In physics, light and its transmission, reflection etc. are introduced much before concepts of colour, which do not appear until perhaps the 12th standard. Of course the prism and splitting of colours comes in somewhere in 9th standard, but again, the focus is not on colours.

Thus, a topic, which may be common to all the three subjects, is never discussed synchronously. It may be important to present a single unit on colour, integrating chemistry, biology and physics for this topic. Also, in order to make the student appreciate the universal nature of colour, it is suggested that the teacher should draw upon a large number of examples from all fields. A few examples are given below, but a teacher can, no doubt, expand this list.

1. Dyes, inks and other chemical examples: Natural and synthetic dye examples can be mentioned. The teacher can show an experiment in class with the familiar diazonium salt and beta naphthol coupling, which produces an azo dye. (This, of course, comes in 12th standard.) Black ink, which is a combination of many coloured dyes, may also be taken up; the separation of this ink into various colours can be shown using a filter paper (Paper chromatography).

Naturally coloured cotton: Coloured cotton, produced in places like Dharwad in Karnataka, may be mentioned. More details can be had from an article by Murthy (Never say Dye: The story of coloured cotton, Resonance, December, 2001).

In the 7th standard, we introduce acids and bases, but perhaps not indicators. Since indicators dramatically change colours depending on pH, they could be mentioned in greater details, with names and the kind of colour change they show. Home-made indicators, such as turmeric and radish leaf extract, must also be mentioned and demonstrated. The student is not introduced to dyes – natural and synthetic, until much later, in the 12th standard.

2. Photo-chromism: Another interesting example is photo-chromism, where changes in colour (or from dark to transparent) are caused by reversible chemical reactions. Such materials are often used in spectacle lenses. Though the student may not need to know the chemical nature of the substances, their names may be mentioned. e.g. azobezenes, spiropyrans and so on. Some of these materials are used in the modern 'Smart Windows' which automatically turn green (or dark) when sunlight falling on them reaches a certain intensity. (We can leave electrochromism for a later stage.)

3. Fluorescence: This is a well-known phenomenon. An explanation can be given in terms of light energy absorption by electrons in a substance, and immediate release of the energy, again, in the form of light. A solution of fluorescein, which is easily available, may be used. Workers at construction sites, as well as traffic policemen, wear overalls with fluorescent paint. This may be mentioned.

4. Colour in lasers: Either from watching TV shows or otherwise, many children are familiar with the word laser. It might be good to give a simple idea of this mechanism, in terms of energy absorption and release by electrons in the form of light. Unlike fluorescence, the release of energy is made coherent by a physical device such that all the photons have the same phase. Thus the emitted light is very intense. Colour in lasers is achieved by choosing appropriate materials with the required electronic energy levels. E.g. He–Ne produces a red colour.

5. Colour as camouflage and display in animals: If we want examples from the life sciences, we could draw upon how birds have colourful plumage to attract their mates; how certain predators blend with their surroundings in order to effectively catch their prey. Similarly, prey also can have colours that help them blend into their surroundings, to escape predators. Of course, the green colour of the leaf and its use in photosynthesis would have already been mentioned many times in the class.

Proposed contents for a combined unit on colour

As we have seen above, there is really a lot to convey about colour at all levels. However, for the middle school, we have to make a judicious

selection from the various aspects of colour; we have to also present them interestingly, without the rigour and the dullness of formulae and equations. At the same time, we have to simplify difficult aspects by just the right amount so that facts are explained correctly.

The following is an attempt to outline the contents of a unit on colour.

Colour

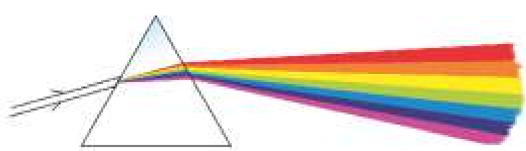
1. Colours around us – natural and synthetic phenomena. – Examples from everyday life

2. Light as a form of energy – infrared heaters, lenses concentrate sun light energy etc. – mention that white light is composed of different colours.

3. (i) What happens when light falls on objects – Transparent and opaque objects – Transmission through solution – Introduce coloured solutions.

   (ii) Refraction – a brief and qualitative explanation, using water (light bending)

   (iii) Dispersion – Experiment with prism – Connection with refraction



   (iv) Reflection of light from opaque objects – Cause of colour in objects – The idea of complementary colours – Explain why objects do not show colours in the dark.

4. Colour and chemistry – Coloured substances (both elements and compounds) in chemistry – as examples, display as many substances as possible; Production of coloured substances – a) inorganic: coloured precipitates such as Prussian blue – Cu-ammonia complex (Copper sulphate and ammonia), nickel dimethylglyoxime (scarlet), barium chromate etc. can be shown b) organic: simple azodye with aniline and β-naphthol can be prepared and shown. Explain, qualitatively, the emission of yellow orange light by sodium lamps. Simple ideas of specific absorption of energy by electrons and re-emission could be brought in if students are familiar with the basics of atomic structure.

5. How do we see – Absorption of light by the photoreceptors in the retina, rods and cones. Sensitivity of cones for various colours.

6. Absorption of red light by green leaves. Explain how the energy produced is used for synthesis of starch – photosynthesis – simple explanation only.

7. Camouflage – Colours on animals and insects.

Notes

1. Origin of the names of colours: The names of colours like red, blue, green, yellow etc. have their origin in languages older than English (as it is known today). These are mainly derived from some languages like Indo-European, Norse etc. A good article on this is to be found at http://www.gizmodo.in/datasearchresult.cms?query=how+colors+got+their+names&sortorder=score

2. Why is the sky blue or red? We know of course that the phenomenon that causes this is light scattering. However, it might be difficult to explain this qualitatively, in words. So, I have not included it in this unit. A partial explanation explaining what scattering means, and that blue light from the sun is scattered more than the others, might be attempted.

Conclusion

In conclusion, it may be said – though a bit optimistically – that this single unit can effectively be used as a bridge between chemistry, biology and physics; and make the job of the teacher easier when discussing other topics in detail.

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NATURE OF SCIENCE

Arvind Kumar

Understanding nature of science is, now, widely perceived to be a vital learning outcome of science education. In this article, we briefly discuss the rationale for introducing 'nature of science' in school science curricula, its evolving perspectives, and the approaches we may adopt to enable the learning of this topic.

Introduction

What is science? It is not uncommon for textbooks of science to begin with this question in the introductory chapter, devote a few paragraphs to it, and then get on quickly with what is regarded as the main stuff of science: its empirical facts, laws, theories, etc. Typically, the books would say: science involves making systematic unbiased observations of nature, doing careful experiments, and drawing logical inferences from them. In this way, we arrive at the laws of nature. We suggest hypotheses to understand the empirical laws, which then lead us to build elaborate theories to explain the known physical phenomena. Theories also predict new phenomena. If the predictions are verified, the theory is confirmed. Science bows to no authority; it is objective knowledge obtained from observations and experiments.

There is much that makes sense in this description of nature of science, simplistic though it will seem as we discuss it further. But first, we must ask why it is necessary at all to teach nature of science when there is so little time to finish the 'more important' parts of the subject.

Why teach 'Nature of Science' (NOS)

To respond to this question, we must pause to reflect on what is the purpose of teaching science in school. Science is a compulsory subject in the Indian school curriculum till the end of secondary school. A majority of students will cease to go for further formal education; of those who do pursue higher stages of education, many would go to commerce, arts and other streams. Therefore, only a small fraction of students finishing Class X will choose to continue in the science stream, and a still smaller fraction of this number will go on to become scientists or other professionals who directly need science and its applications in their careers. Thus most people are unlikely to need any scientific content knowledge (of the kind learnt at school) in their professions.

Why, then, have we made science education compulsory at the school level? Clearly, this would make sense only if the main purpose of school science education was somewhat broad and not limited to specific science content only. The goals of school science education have been debated endlessly, often with differing ideological stances; but few would disagree that a principal goal is to

generate an informed science citizenry in the country. Students need to grow into citizens who have a feel for what science is about, what methods and processes are involved in generating new science, and what relation science has with technology and society. This has become increasingly necessary, because science and technology are deeply impacting our ways of living. Citizens need to have some minimal familiarity with modern technology, its possible benefits and risks; its impact on our health and environment, etc.; so that they can make informed choices, and formulate mature opinions about these issues. Science, some would argue, has ushered in the Age of Reason, and can help encourage a rational outlook about life (though at present this seems like a distant goal!). These, and several other allied objectives, are sometimes, clubbed under the head 'science and technology literacy'. There are numerous variants of this term, and many shades and nuances, but, perhaps, it is safe to say that the rationale for teaching NOS is tied closely to this general goal of school science education.

Does that mean we incorporate the teaching of NOS at the expense of the 'real' content of science? In doing so, do we not jeopardise the quality of knowledge of our future scientists? Will our country not lose out on its competitive edge in science? And, in any case, will the teaching of NOS be of any real use for the larger majority of students we have in mind?

These concerns, widely shared among teachers (and scientists), arise naturally because the relevance of NOS in the school science curriculum, and its pedagogy, are still not very clear. First, it is not correct to think that NOS is relevant only for the non-science group indicated above, and that future scientists need to focus only on acquiring conceptual knowledge that is at the core of their subject. On the contrary, there is an increasing feeling among educators that learning NOS can deepen one's understanding of the subject itself. For the past few decades, science education researchers have carried out detailed studies at different levels, on the epistemic and ontological beliefs of students with regard to their subject,

Francis Bacon's work established the Scientific Method

By epistemic beliefs we mean our ideas on how scientific knowledge is generated and justified; by ontological beliefs we mean broadly our ideas on the basic categories of objects that exist in nature. For example, classical physics regards particles and electromagnetic waves as two distinct ontological categories, a distinction that gets blurred in modern physics.

and have concluded that these could have a bearing on their critical understanding of the content of the subject.

In short, understanding nature of science is not only relevant for the general goal of promoting science and technology literacy; it is just as relevant to a science student, in developing a deeper appreciation for her subject.

Second, what is envisaged is not to 'dilute' the content of science, but rather to use it imaginatively, as a means to teach NOS, among other things. In other words, NOS is to be taught, not by preaching abstract generalities set aside in a separate unit of the book; it is to be put in context by interleaving it with the content of science. Before we see how that might be done, we must first broadly agree on what our views are on 'nature of science'.

Nature of science: evolving perspectives

The nature of science has been a subject of philosophical inquiry all through history, and continues to be so, even now. As science has advanced, particularly in the last four centuries, so have our ideas about the nature of science. When, in the 16th and 17th centuries, modern science was being shaped by the work of Galileo, Descartes, Kepler and Newton; Francis Bacon was formulating, what we now call, the scientific method. Roughly speaking, the introductory paragraph of this article replicates Bacon's ideas of nature of science. The essence of Bacon's ideas is that science is

inductive generalization from unbiased observations of nature, and controlled experiments. Bacon foresaw the immense power of this new method in not only predicting, but also controlling phenomena.

In the beginning of the 20th century, an influential group of philosophers of science undertook to formulate a more rigorous version of the scientific method. Briefly, they regarded a statement or an assertion meaningful only if it was either logically self-evident, or could be put in a verifiable form; science must only have such meaningful statements. For convenience, we may use theoretical terms like 'atom', 'gene', 'valency', but ultimately, all scientific assertions must be reducible to observation statements. By this strict criterion, poetry is meaningless, if harmless, while a metaphysical assertion is both meaningless and harmful, since it purports to be true! The proponents of this philosophy, called logical positivism (and in its later, more moderate, version, called logical empiricism), could not realise their ambition of translating all of science in these terms.

In the same spirit of analysing the scientific method, but distinct from logical positivism in many ways, was the philosophy of Karl Popper. Popper was driven by a desire to differentiate between science and, what he regarded as, pseudoscience. He is famous for his falsification criterion: a theory is not scientific if there is no way to refute it. Good scientific theories give unambiguous predictions that are falsifiable. If the prediction is verified, you have not confirmed the theory; you have simply not shown it to be false yet. This is precisely where pseudo-sciences differ—they do not give clear-cut testable predictions, and can accommodate any observation. Popper advocated that science should 'stick its neck out', give bold new predictions, and suggest critical experiments that have the potential to falsify a theory. Popper was inspired by Einstein's work, and his ideas usually resonate with scientists; he is often called the scientists' philosopher.

In an incisive criticism of these dominant ideas, around the 1950s, Quine argued that a scientific theory is a complex web of interconnected assumptions and claims that relate to experience as a whole. Consequently, it is not possible to test or falsify each statement of the theory in isolation. He called for a holistic theory of meaning and testing.

Philosophies seeking a rational basis of science, clearly separated the context of discovery (the intuitive creative phase of science embedded in particular social settings) from the context of justification (critical philosophical scrutiny of theories claimed to be correct). The former was thought to belong to the realm of psychology /sociology. This distinction kept the actual practice of science, largely, beyond their purview. In other words, the attempt was to formulate what the scientific method should be, rather than what it was actually.

Around 1960s, Thomas Kuhn's, now famous, book 'The Structure of Scientific Revolutions', marked the beginning of a major transformation of our ideas of nature of science, and how it progresses. Analyzing some key milestones in the history of science (such as the Copernican revolution), Kuhn concluded that scientists normally work within a certain paradigm; they are conservative up to a point, and do not abandon their existing theories even in the face of some anomalies (disagreement with experiment). However, when the anomalies are stark and accumulate with time, there is a crisis in normal science, and the existing paradigm is questioned. All kinds of alternative ideas float during the crisis, out of which some promising new ideas begin to attract consensus, often because of some particularly striking exemplars. A new paradigm is born, and normal science returns, in which scientists work out the details and applications of the changed paradigm.

The key point to note in Kuhn's philosophy is that the paradigm shift is not governed by a purely rational process; it involves a social consensus in the scientific community. The adherence to an existing paradigm in normal science is secured through training in our colleges and graduate schools. Not everybody agreed with Kuhn. Lakotos found the undermining of the rational basis of scientific progress implied in Kuhn's ideas unacceptable, and developed his own theory in terms of the notion of competing 'research programmes'. Feyerabend dismissed the very idea that there is any clear method in the way science evolves. His philosophy is often summarized by the catchy line: 'anything goes'. His noted book 'Against Method' celebrates creativity in science and advocates freedom of imagination. Thus while Lakotos found the disorder inherent in Kuhn's view of science alarming, Feyerebend criticized Kuhn for just the opposite reason-- for his orderly and mechanical view of scientific

progress. Normal science had a very significant role in Kuhn's scheme, since it goes deep into an accepted paradigm, making it possible to discover anomalies that eventually result in changing the paradigm. Feyerebend, on the other hand, criticizes the routine mind-numbing activities of normal science, and asserts that science progresses through creative leaps of imagination that defy existing ideas.

Whatever the merits of Kuhn's theory, it was certainly responsible for introducing a sociological dimension to philosophy of science, in the second half of the 20th century. Indeed some sociologists viewed the standard philosophy of science as irrelevant, and asserted that we can understand nature of science only by a critical and detailed probing of the actual way in which scientists work. This development has taken the debate on nature of science in many different directions that we cannot adequately describe here. But, we certainly have a better perspective now on the socio-cultural norms that enable science to grow. For example, it seems clear that the formation of robust social institutions of science (Scientific Societies in Europe, such as the Royal Society) practising norms of open and democratic discussion, peer reviewing of research, and communal ownership of scientific laws, etc. was as crucial for the growth of science, as the ingenuity of individual scientists.

We can summarise some new insights on nature of science that have gradually emerged from these discourses. First, science is not just induction from observations and experimental data; it often involves imaginative and radical new ideas not necessarily suggested by them. For example, some of the most successful theories of science have arisen from general considerations of simplicity and symmetry, and a drive for unification. Second, though observations of nature are often the starting point, not all observations are neutral - they are 'theory-laden'; theories, implicitly or explicitly, guide us to where and what to experiment and observe (this does not necessarily undermine the objectivity of science).

Third, observations and experimental data underdetermine correct theory; several different theories can all be consistent with them. Fourth, science is not a purely cognitive endeavour; though it is certainly constrained by the empirical facts of nature, it also involves some social consensus among scientists and needs enabling socio-cultural norms and conditions for its growth. Fifth, science, technology and society (STS) are intertwined in complex ways, affecting and being affected by one another. A corollary of the last point is that we must be alert to the possible pitfalls in scientific practice and the harmful consequences of uncritical and unwise use of technology.

This brief overview is intended only to give a flavour of the subject; it admittedly does not capture the many subtle aspects of philosophy of science. See, for example, Godfrey-Smith (2003)[1] for a deeper treatment of this subject, and for references of the classic works mentioned above.

Nature of science: how and what to teach

With so much of the historical debate on nature of science continuing into the present, what is it that we wish students to learn about NOS in school education? Obviously, we cannot import the complex philosophical issues on the matter into our classrooms. There has been much reflection on this point, and the feeling is that despite the wide range of perspectives, there is a core of generally accepted new ideas in NOS that are learnable by young students. We recommend referring to the New Generation Science Standards NGSS (2013)[2] developed in the U.S.A. Of course, similar objectives have been advocated elsewhere; see, for example, Pumfrey (1991)[3], Osborne et al (2002)[4]; and also Taylor and Hunt (2014)[5]. For a much deeper perspective on the subject, see Erduran and Dagher (2014)[6]. We summarize, here, what in our view appears to be a broad consensus; more details on NOS objectives can be found in the references cited.

<u>Nature of Science Objectives (Summary)</u>

Students should appreciate that…

<u>Scope</u>

…Science seeks to describe and explain the physical world based on empirical evidence. Some domains may be beyond its scope.

<u>Methods</u>

…Science adopts a variety of approaches and methods; there is no one universal method of science.

Science does not involve induction only. Creativity and imagination are equally important in generating hypotheses and building theories.

Observations and experiments are often insufficient to determine a theory.

Science involves expert judgements, and not just logical deductions. Hence there can be disagreement.

Social aspects

...Science is a co-operative multi-cultural human enterprise to which countless men and women contribute, including some noted individuals who play a significant role. Social institutions practising norms of open debate, peer reviewing and common ownership of knowledge are vital for its growth.

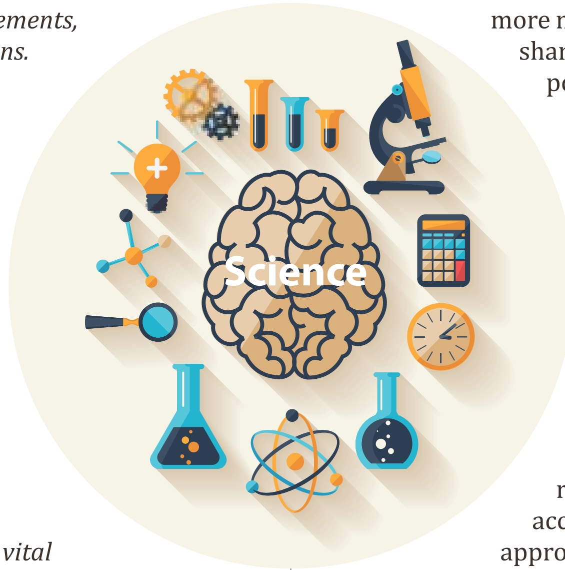
Science and technology may lead to issues that need socio-cultural resolution.

Scientific knowledge

...is dynamic and subject to revision by new empirical evidence.

Finally, the most important but difficult question: what pedagogy is to be employed to teach NOS? The idea that content alone is not enough in science education is not new, as the history of curriculum reforms since the 1960s (or even earlier) shows. Around the 1970s, some educational reforms emphasized processes of science more than its content: observing, measuring, classifying, analysing, inferring, interpreting, experimenting, predicting, communicating, etc. Soon there were critical appraisals of this approach; some educators questioned the very premise that there are a set of general transferable processes common to all sciences. See, for example, Millar and Driver (1987)[7]. For some time now, there seems to be a broad convergence on an Inquiry-based approach to science learning and teaching. This approach, informed by the constructivist philosophy, no doubt, involves learning the processes of science mentioned above; but it goes much further, to include posing questions, critical thinking, giving evidence-based explanation, justifying it, and connecting it to existing scientific knowledge, etc. Basically, this approach advocates the learning of science in a manner that resembles the way scientists carry out their investigations.

Inquiry tasks are naturally relatively simple for younger children, and quite elaborate for the more mature students, but they share the common feature of posing a question and seeking an evidence-based explanation. They can have different foci; some may relate to STS issues, while others may be more discipline-oriented. Inquiry may also include reflections on the inquiry mode itself, and thus naturally incorporate NOS educational objectives. We refer the reader to a critical account of the Inquiry approach, including its relation with NOS, in Flick and Lederman (2006)[8].



Another approach uses the History of Science (HOS) as a means to teach NOS. This again is not a new idea; see the excellent book by Holton and Brush (2001)[9]. Some key points in its favour are thought to be: HOS involves human narratives which enliven science and engage students' interest; it often has parallels with students' spontaneous conceptions and thus helps us in anticipating and remedying their content-specific ideas; knowing how present science arose from competing ideas at different times in history can promote critical thinking; and lastly, HOS is the most natural setting for learning NOS. We refer the reader to a comprehensive Handbook brought out recently on this issue (Matthews 2014)[10].

As Lederman (2006)[11] has forcefully argued, NOS objectives should be regarded as primarily cognitive outcomes that can be properly assessed. Instruction needs to bring them out explicitly, they are unlikely to be assimilated implicitly, whether we adopt an Inquiry or a History based approach. A whole range of inquiry tasks and HOS based vignettes, explicitly focussed on NOS; need to be developed if we aim to improve student understanding of nature of science.

Acknowledgements

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Flatus: Beware!

Flatus is the gas generated in, or expelled from, the digestive tract, especially the stomach and intestines. More than 99% of human flatus comprises nitrogen, oxygen, hydrogen (hydrogen-consuming bacteria in the digestive tract may consume some of this to produce methane and other gases), carbon dioxide, and methane.

During World War II, US fighter pilots flew at increasing altitudes. The associated reduction in the (external) atmospheric pressure allowed the digestive gases trapped in their intestines to expand (Boyle's law), causing very painful cramps. Foods known for their ability to produce flatus – dried beans and peas, vegetables of the cabbage family, carbonated drinks, and beer – were therefore removed from pilots' menus.

Methane is a combustible gas (e.g. a good fuel for Bunsen burners), although it is produced by only about one-third of people in the Western world. In the early days of the space race, there was some concern that the methane emitted by astronauts, if accidentally ignited, could cause an explosion within the spacecraft. No such incidents have occurred to date. However, exploding flatus has caused the accidental death of at least one surgical patient. An electrode touched to the patient's colon ignited the hydrogen and methane it contained, also causing the surgeon to be blown back to the wall of the room.

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A MEETING WITH THE MACROPHAGE

Vignesh Narayan H.

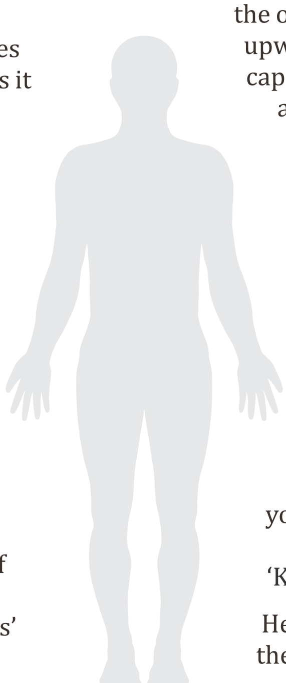
The human body is an eternal battleground. We are constantly meeting with invaders of all kinds and all sizes. Did you know that our bodies have private armies that fight against disease? What are the different units in this army? How do they function? How do they get to the frontline almost instantaneously? These questions and many more are answered in this first-hand account by a soldier (cell) in the human immune system.

"Enter at your own peril, through the bolted door where impossible things may happen, that the world has never seen before!"

- Theme song of 'Dexter's Laboratory' animated television series

Have you ever wondered what goes on inside your own body - how is it that you can gulp down some orange juice and feel the cool waves of freshness coursing down your throat, read this line, and think about the next IPL cricket match, all at the same time? Scientists have discovered that 75% of the cells in our bodies are bacterial, and only 25% are human. Does this make us more bacterium than human? What is it that really makes us who we are? Let us find out at least some answers.

Today, I'll introduce you to a friend of mine. We call him 'big M', but I guess you can call him 'Macrophage'. In the world of the human body, he makes up a small portion of white blood cells or 'leucocytes' that are part of your body's defence system. You can talk to him yourself. All you have to do is travel down your trachea, also called your 'wind pipe', until you reach one of your lungs (let's turn right at the cross-roads). The road ends at an alveolus or 'air sac', which is the destination for the oxygen you breathe. From there, turn upwards and squeeze out through the capillaries (tiny blood vessels that line the alveoli and carry away the oxygen to other parts of your body), travel through the soft pink tissue until you reach the sternum. The sternum is the giant bone that is in the centre of your chest, holding the ribs together and forming the main pillar of the rib cage. Knock on the sternum twice, and ask for the blood monocyte. He'll come, for sure. I have informed him, in advance, that you are going to pay him a visit; he is a good friend of big M, and will take you to see him.



'Knock knock'

Hello there! How nice to see you. You want the blood monocyte? Why, here he is before

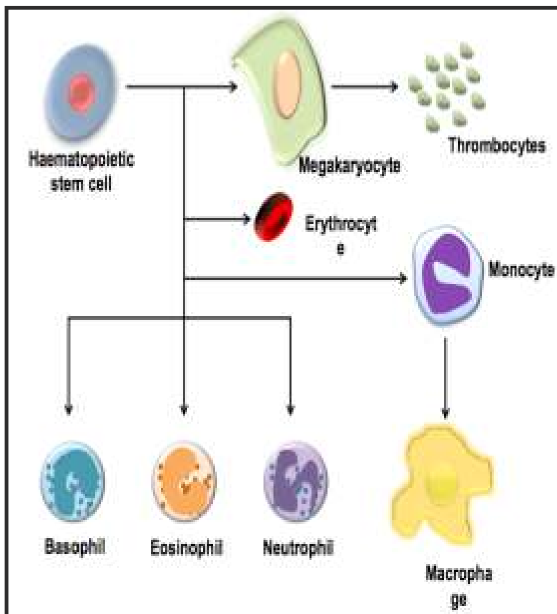
you, in the flesh, or should I say, in the protoplasm! Of course Sir, it is me that I'm talking about. My name is monocyte, and I'm honoured that you have travelled all the way to the sternum to see me. I live further down, past the hard bone tissue, right at the centre, where the walls are soft, the blood nice and warm, and everything is a bright red. We call it 'the marrow'. You must pardon the dreary colour choice, everything in here is red. This, as you know, is because all the red blood cells in the blood stream are produced here. Well, not only here, but in other bone marrows all over the body. This happens to be one of our larger factories, where the process of 'haematopoiesis' takes place. It is a horribly complicated word for a horribly complicated thing. Haematopoiesis (pronounced heem-ato-po-es-sis) is the process where our fathers, amazingly versatile cells called 'multipotential haematopoeitic stem cells' underwent a series of orderly cell divisions (one cell becoming two) and cell differentiations (one type of cell - such as a stem cell - becoming another type of cell - such as a leucocyte) to produce myself, and all my kin. Together, we are called blood cells. We, blood cells, are divided into several categories, naturally because we carry out several different functions.

'Thrombocytes' or platelets derive their name from *thrombos*, the Greek word for blood clot. They are the tiniest of blood cells, and are only 20% of the size of red blood cells. Platelets disperse throughout the entire blood stream, ready to form blood clots wherever blood vessels are damaged. This is very important to prevent the loss of blood when there is a wound, or to prevent leakage of blood into the surrounding tissue, in case blood vessels spring leaks.

'Erythrocytes' are red blood cells. These cells are produced in huge numbers, and it is because of them that the entire body is red. Without them, every tissue in the human body would be white, or yellow, or straw coloured in places where there are many fat cells. Did you know that at any given time, the body contains approximately 20-30 trillion red blood cells? That is 20 followed by 12 zeroes! Haemoglobin, found inside red blood cells, binds iron, which gives a red colouration when it is bound with oxygen. In fact, this bond between iron and oxygen is the way that oxygen is transported from the alveolar capillaries that you saw in the lungs to all other parts of the body. Many diseases occur in the human body when these red blood cells cannot accumulate haemoglobin optimally, leading to a deficiency in oxygen throughout the body.

Oh my, look at the time! I've been rambling, I really do apologize. I still have so much to tell you before we meet big M. You see, big M is a man of business; he does not like questions if he thinks that the answers are trivial. Most of the people who come here to talk to him are scientists working on larger problems in healthcare and disease. Just the other day, there was this PhD student who wanted to know how big M detects the *E. coli* lipopolysaccharide! I myself have no idea what that means, but, big M - he knows everything! So before we actually meet him, I'll have to tell you all about him and the rest of my brethren. The last thing we want is for you to ask him who he is when you meet him!

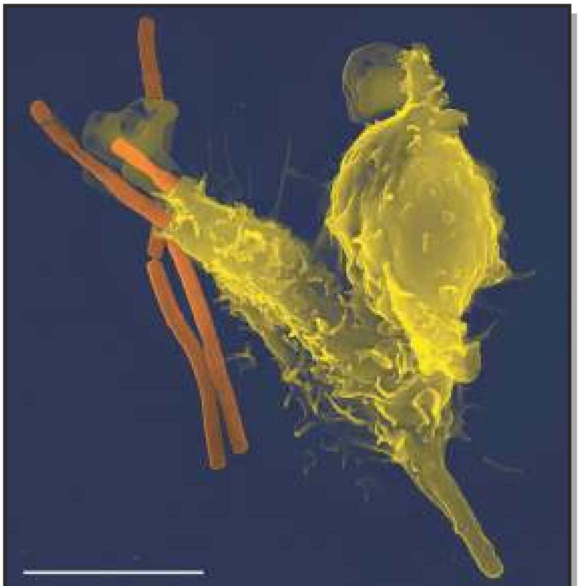
Big M is part of a family of defence cells, called white blood cells. You could think of him as my elder brother, which is why most people ask me to take them to him. The other cells won't do it, because they are afraid of his 'cytotoxic' potential; I'll tell you what that means as we go along. Our family tree has myeloid leucocytes as well as lymphocytes; all on the paternal side (remember our fathers, the multipotential haematopoeitic stem cells?)! The myeloid (my-ee-loyd) leucocytes include the monocyte - that is me, Big M - the macrophage, and our three cousins - the neutrophil, the eosinophil and the basophil. Our family, I am proud to say, has been the first line of defence for the body since the day it was born. We



The process of haematopoiesis – where the parental haematopoietic stem cells divide and differentiate to give rise to all the other cells found in the blood

have had help from elite forces called lymphocytes, but that has only been during serious battles, when we were being overpowered. Can you imagine living on the borders of this land, so far away from home, always waiting and watching, and expecting an attack at any moment? Well, that is the life we lead.

My cousin, the neutrophil, is like your foot soldier on the outside. He is the first to enter into a skirmish, and sadly, his family counts as the first to give their lives to protect the body. Have you seen pus - the thick sticky white fluid that oozes out of an open wound or a gash? Well, that is

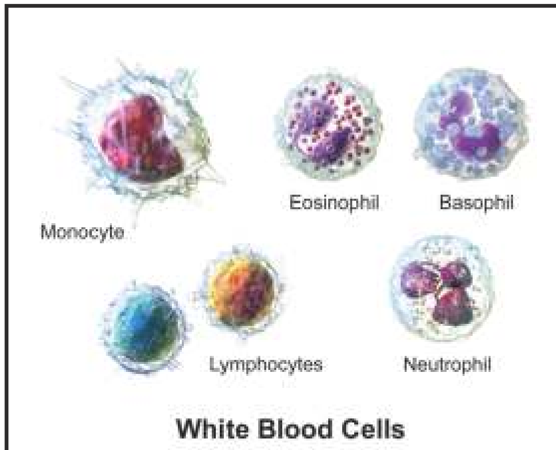


Neutrophil Engulfing Anthrax Bacteria

Volker Brinkmann – (November 2005). "Neutrophil engulfing Bacillus anthracis". PloS Pathogens 1 (3): Cover page. DOI:10.1371. Retrieved on 2009-01-04. Neutrophil engulfing anthrax bacteria, taken with a Leo 1550 scanning electron microscope. Scale bar is 5 micrometers. Creative Commons Attribution 2.5 Generic

formed by neutrophils dying in huge numbers, taking the enemy forces with them. Be very careful when you get a wound that starts oozing pus, because that means that the neutrophils have started dying and the body has to call the second line of troops. Keep the wound clean, wash it with antiseptic, otherwise the invaders may travel further inside our borders.

Have you ever wondered what kinds of enemies invade our home? Almost every invader you can think of wants food and shelter! If you give them an inch, they'll take a mile. Just the other day we met a huge nematode worm that had entered as tiny eggs in food. The food was not cooked properly, and the worm eggs survived (this happens mostly in meat, like pork and beef; and green leafy vegetables that are grown in dirty water). That was when my brother eosinophil swung into action. Armed with proteins that are highly toxic to worm parasites, he ejected toxic vesicles (small sacks containing poisonous stuff!) which exploded like hand grenades, at the worms, killing them instantly. He was awarded the medal of valour, and given a 2 hour vacation (2 hours is pretty long in the life of small cells like us)! Of course, there are those in my family who don't have such heroic tasks, and are few in number. I am talking of eosinophil's brother, the basophil. There are so few basophils here, and their numbers are always lower than the eosinophils and the neutrophils. The basophils however,



Source: https://en.wikipedia.org/wiki/White_blood_cell - Creative Commons Attribution 3.0 Unported Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762

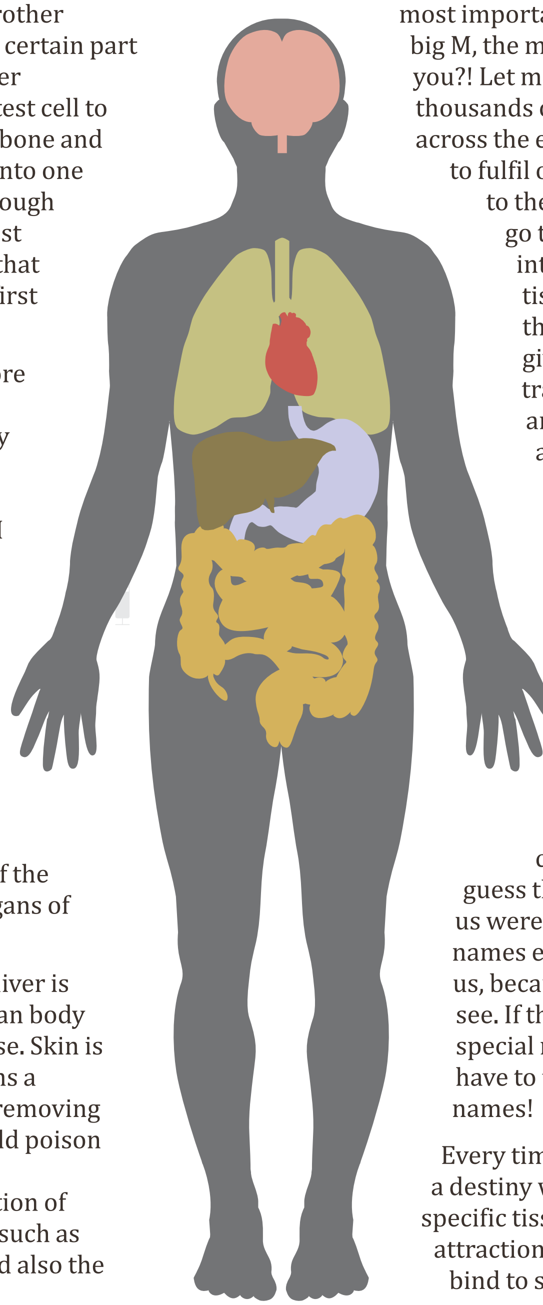
perform a very important function. They act as 'messengers of inflammation'. An inflammation is like an SOS signal or a 1-0-0 call to the police control centre. Whenever your body gets itchy or red in places, with swelling or heat, or even whenever you have a runny nose and a horrible cold, you should know that cousin basophil is doing his job and rallying the forces of the body to battle against disease.

Well, I think we have almost completed a brief tour of my family tree! It is as well, because we have almost reached the liver, where big M awaits

us. I have modestly left out a description of my own humble self, the monocyte. It won't be an exaggeration to say that I am the largest of all the cells in the blood. The head office has entrusted me with two responsibilities, which is more than what most of my cousins can handle! We, monocytes, can change our nature at a moment's notice. On a normal day, I look just as you see me now, clear and transparent, without any defined shape (like an amoeba, another parasite that brother neutrophil constantly fights against). This 'shapeless shape' of mine is very useful in squeezing through tight places like blood vessels, and navigating through tightly packed tissues. Whenever brother basophil raises an alarm in a certain part of the body (do you remember inflammation?), I am the fastest cell to reach his calls. Dashing past bone and cartilage and fat, squeezing into one vessel and squeezing out through another, I can find the shortest path to any part of the body that needs my help, which is my first function.

My second function is far more interesting. Once I reach the site of inflammation, I use my powers of bodily transformation to do something quite amazing, if I do say so myself! I won't tell you about it just yet. Instead I'm going to give you a live demonstration once we reach our destination. Just behind that large membrane, called the diaphragm (di-a-fram), is where we are going, to one of the most important and vital organs of the body - the liver.

In case you didn't know, the liver is the largest organ of the human body (apart from the skin, of course. Skin is just everywhere!). It performs a myriad of functions such as removing harmful substances that could poison the body (a process called 'detoxification'), metabolization of various components of food such as carbohydrates and lipids, and also the synthesis of cholesterol and other proteins and hormones. In fact, during the first trimester of the foetus (the first three months of a baby's life inside the womb), the liver even produces red blood cells (which as you now know, is produced in the bone marrow of adults, where you met me)!



Ah! We have reached at last!

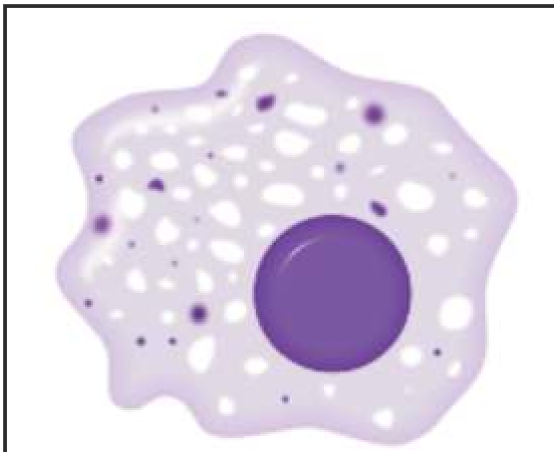
BEHOLD! IT IS I YOU HAVE TRAVELLED SO FAR TO MEET! As you can see, I have been growing bigger and bigger ever since we have entered the liver. Using subtle chemical signals present in the liver tissue that only I can see and respond to, I have transformed into one of the body's most important soldiers. I have become big M, the macrophage. Surprised, aren't you?! Let me explain. Every day, thousands of monocytes, like me, journey across the entire span of the human body to fulfil our destinies. Some of us come to the liver as I have done; others go to the bones, the brain, the intestines, and virtually every tissue in the body that you can think of! Some of us are even given different names when we transform into macrophages. I am called a Kupffer cell, named after the German scientist who first found me in the liver. My brother macrophages in the bones and the brain are called osteoclasts and microglia respectively. A few others have no special name, for example, macrophages that reside in the alveoli (remember your journey down the wind pipe into the lung?), are called alveolar macrophages. I guess the scientists who discovered us were tired of thinking up new names every time they spotted one of us, because we are everywhere, you see. If they had to give each of us a special name, I am sure they would have to think of more than twenty names!

Every time a monocyte is made, he has a destiny which draws him towards a specific tissue in the body. This attraction is through chemicals, which bind to special molecules on our cell

surfaces, called receptors. Whenever we feel the presence of these chemical molecules, we are pulled towards the source of that chemical. In this way, cells in the bone call on monocytes to migrate into the bone tissue, and transform into osteoclasts. Cells in the brain secrete chemicals that welcome monocytes into the brain to become microglia. I was quite young when I felt my first pull. Almost as soon as I was born, I knew that my home was the liver, and my destiny was to safeguard the cells in the liver by transforming into a Kupffer cell.

My job is simple. It is no secret that I am always hungry - look at my waistline! I am here to defend the body against any external agent by doing what I do best, eating everything in my path. My very name means 'big eater', and that is all I do. The liver, you see, is one of our most strategic battle stations against the outside world of bacteria, fungi, parasites and toxins. Here in the liver, we constantly face a barrage of blood-borne pathogens (pathogens are disease causing organisms), mostly from the gut. Just to show our importance, scientists, studying our role, have experimented with removing all the Kupffer cells from the bodies of some lab mice. The results were shocking to them, but quite obvious to me. All the mice died. Which is why we have a saying here, in the immune system (the immune system is the body's army), *"you can live without a femur (the longest bone in the human body, located in the thighs), but you ain't got no chance without a Kupffer in the liver."*

I have a lot of company here, because the liver is the organ with the largest population density of macrophages in the human body. We need to keep our numbers high, of course, because almost everything that enters the body through the blood or the food (and a lot of them do!) head straight to the liver, where we await them. Let me explain the process by which we protect you from all that is harmful and disease causing. As soon as we see a foreign object (a bacterium perhaps), we engulf it in a process called 'phagocytosis' (fag-o-cyto-sis). Once inside us, the invaders don't stand a chance. We trap them inside specialized sacks inside our bodies, called phagosomes. The phagosomes are, then, flooded with a deadly concoction of enzymes and acids that lyse (break open), and



Drawing of a macrophage when fixed and stained by Giemsa dye.

Source: https://en.wikipedia.org/wiki/Macrophage

digest virtually every part of the invading specimen! Sometimes when we face a foe that is especially difficult to kill, we produce a harmful mixture of reactive oxygen and nitrogen radicals (molecules that are highly charged and reactive) in a process, called 'oxidative burst'. If our acids don't kill them, the oxidative burst surely will. Of course, the oxidative burst damages us as well, and it is only during really harsh battles that we resort to this suicide bombing strategy. The reactive oxygen and nitrogen radicals explode into the surrounding tissue, killing all the human body cells present nearby. This is why, getting rid of a disease is often tiring, and makes the body weak. Remember to always rest well and fully recover, so that your body has time to repair the damage of the day's battle; because there is a battle being fought by your immune system, almost every day

Now, if you will please excuse me, I have to go eat some bacteria! The narrator will show you the way out. Begone!

Shall we take a roller coaster ride through the nervous system? Or drift lazily down the canals of the heart? Until we meet next time, remember that every second of every day, big M and his friends in the immune system are fighting for you.

Goodbye.

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INDIA'S MARS ORBITER MISSION

Anand Narayanan

It was a proud moment for India, when the Indian Space Research Organisation launched the Mars Orbiter Mission (MOM), the first one ever to successfully position a satellite in an orbit around Mars. Why Mars? What makes this planet more special than our other neighbours in the solar system? What do we hope to learn from exploring another planet? This article explores some of these questions on interplanetary explorations, while also building an understanding of space science in practice.

Introduction

On September 24, 2014, India crossed a major milestone in space exploration. India's first interplanetary mission, MOM, entered into orbit around Mars, putting the Indian Space Research Organization (ISRO) in the same league as the American, European and Russian space agencies, the only ones ever to have accomplished a similar feat.

ISRO described MOM, and its journey of 650 million kilometres, as a technology demonstrator mission and not so much as a science mission. India had never done it before. Technologically more advanced countries, like Japan and China, had attempted, but failed, in placing a satellite in orbit around another planet.

Interplanetary travel is a tricky venture. Designing a trajectory for an eventual encounter with a planet at a distance of a million kilometres from us is no minor task. The fact that we are on a moving launch platform (the Earth), with the target also moving relative to us, increases the complexity of the trajectory calculations involved.

With the success of MOM, and the earlier Chandrayaan mission, ISRO has demonstrated its technological capability for deep space communication and navigation. Along with that, it has also established the reputation of the Polar Satellite Launch Vehicle (PSLV) as a trustworthy carrier of satellites for interplanetary travel.

There are many scientific lessons one can learn from the success of this single mission. This article features a few of those.

1. Why Mars?

From the point of view of distance from the Earth, Venus is closer to us than Mars. Why then did ISRO pick Mars over Venus for its maiden interplanetary mission?

There are two main reasons for this:

1. From a scientific exploration point of view, Earth shares more with Mars than it does with Venus. Mars, thus, provides plenty of opportunities to understand the geological and biological processes that could have shaped the evolution of Mars as well as Earth. Mars also presents an excellent case to search for life outside of Earth.
2. Compared to Venus, it is easier to gather information about the terrain and surface features of Mars from a high altitude orbit.

1.1 An Earth sibling of the past

The most compelling reason for investigating Mars is that in many ways in its past, Mars had a close semblance to Earth. Also, Mars rotates once around its axis in approximately the same 24 hour duration as Earth. This means that the day and night cycle on Mars is similar to Earth.

Like Earth, Mars also has seasons, because its spin axis is tilted at an angle of 25 degrees. When it is winter in one of the poles, ice forms and grows in size. During summer when there is more direct sunlight for longer durations, this ice cap melts.

The following image of Mars was taken by the Hubble Space Telescope. It shows how ice caps on the North Pole of Mars grow and recede with winter and summer seasons.

nearly one-third of the Martian surface could very well have been covered with oceans.

The obvious question then is **where did all this water go?**

There are no definitive answers, although the small size of the planet could be a major reason for Mars's global transformation - from a warm and wet planet to the cold, dry environment that we see today.

Mars, presently, has a very thin atmosphere, mostly composed of carbon dioxide (CO_2) gas. The atmosphere is so thin that the pressure on the surface of Mars is only about 1/1000th the atmospheric pressure at sea-level on Earth. But the circumstances may have been quite different in the past.

Mars currently has a dry surface, but there are many pieces of geological evidence on this planet that suggest that there was once liquid water flowing over it. Satellite images show winding channels at several locations on the planet. The winding channels look very much like dried up river beds, lake deltas and gullies carved by flowing water. Geologists hypothesize that the climatic conditions on Mars were, at some time in the distant past, suitable for liquid water. In fact,

It is most likely that Mars had a dense CO_2 atmosphere (a greenhouse gas) in the past, which kept the temperatures on its surface high enough for water to exist in liquid form. Over time, the strong impact of solar winds (the constant stream of charged particles from the Sun travelling at speeds of several hundreds of kilometres in one second), must have slowly eroded the gases from the Martian atmosphere. Being a small planet, Mars had a very weak magnetic field, insufficient

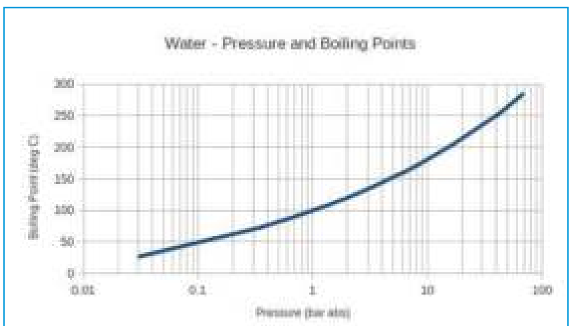
to shield the planet from the charged particles of the solar wind, in the way that the Earth's magnetic field shields our own atmosphere. Furthermore, the low surface gravity of Mars meant that it could not hold onto gases as they gradually drifted out into space.

For a visual account of the atmospheric loss processes, watch the NASA Goddard videos at https://www.youtube.com/watch?v=ogcaSmofPo4 and https://www.youtube.com/watch?v=0_iz5Nt0Qc8

How is Atmosphere Loss measured?

By measuring the ratio of abundance of deuterium to hydrogen (D/H), scientists are trying to estimate the rate at which Mars is currently losing whatever is remaining of its atmosphere. Deuterium, being twice as heavy as hydrogen, will be lost at a slower rate compared to hydrogen. By starting from a realistic assumption of the initial D/H ratio in the Martian atmosphere and by measuring the current value for this ratio, the past rate of atmospheric loss can be assessed.

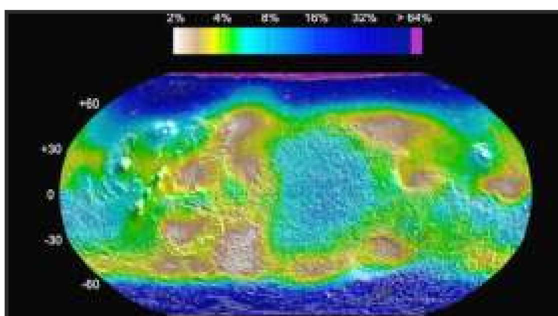
As the density of the atmosphere lowered, water in liquid form would have directly been converted into vapour. The temperature at which water turns from liquid to vapour phase, called its boiling point, is pressure dependant, as shown in the graph below. As the atmospheric pressure on Mars dropped, its ambient temperatures were high enough to evaporate the water on its surface. All the water vapour produced in this way gradually escaped into outer space.



From ice to vapour avoiding liquid

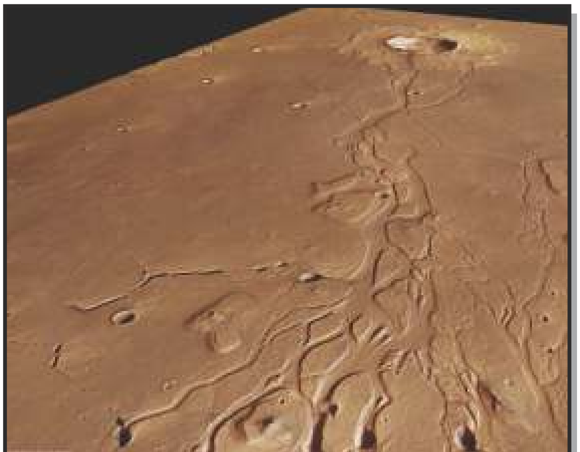
The temperature at which ice turns into water is called the melting point of water, and the temperature at which water turns into vapour is called its boiling point. Both these temperatures of phase transition depend on the ambient atmospheric pressure. Under low pressure conditions, both the melting and the boiling point will get reduced. Pressure on the surface of Mars is less than 1% of the atmospheric pressure at sea level on Earth. Under these low pressure conditions, as the polar ice caps melt, both the CO_2 and H_2O in ice are directly converted into their vapour form. This process is known as sublimation.

Although, a good fraction of the surface water on Mars has evaporated, scientists speculate that there may still be substantial reservoirs of water in liquid form several thousand meters below the Martian surface. Significant fractions of this water are in the polar regions of the planet, beyond about 60 degrees latitude north or south, as the next figure shows.



Mars_Water_Map: This is a global map of the Martian soil showing lower limits on the water content. The estimates are derived from the hydrogen abundance measured by the neutron spectrometer component of the gamma ray spectrometer suite on NASA's Mars Odyssey spacecraft. The highest water-mass fractions, exceeding 30 percent to well over 60 percent, are in the polar regions, beyond about 60 degrees latitude north or south. Credit: NASA

Water is considered an essential ingredient for the emergence and evolution of life as we know it, here on Earth. Hence, finding water or any evidence for its presence on Mars, has remained a major goal for all Mars missions.



Photograph taken by the Mars Global Surveyor robotic spacecraft which is currently orbiting Mars. On the surface are numerous channels that resemble flow channels on Earth. These marks could be a result of flow of water on Mars in the past. Photo Credit: JPL, NASA.

Photograph of Martian surface taken by a high resolution stereo camera onboard European Space Agency's Mars Express. Along with flow channels from water that once flowed on the surface. One can also see some impact craters possibly produced by impact of asteroids with Mars. Credits: ESA/ DLR/ FU Berlin (G. Neukum).

1.2 A bird's eye-view of what is below

Another reason that makes Mars a compelling target, compared to Venus, is the convenience of collecting information about the terrain and surface features once the spacecraft settles into an orbit around the planet.

Venus has a very dense atmosphere. The pressure from the atmosphere on the surface of Venus is estimated to be about 90-100 times the atmospheric pressure on Earth at sea level. Several layers of dense clouds envelop the surface, like a thick blanket. Instruments on board a spacecraft orbiting the planet from a high altitude will not be able to peer through this opaque covering for a clear bird's eye view. This seriously hampers the scientific possibilities of an orbiter mission.

The atmosphere of Venus is also not favourable for landers (spacecrafts that land on a planet surface). The presence of large amounts of CO_2 in Venus's atmosphere has created a strong greenhouse effect on the planet. The average temperature on Venus is 450 degree centigrade, making it the hottest planet in the solar system, hotter than even Mercury. In addition, there are also strong winds that blow at speeds of 300 kilometres per hour and more, which keeps the atmosphere highly turbulent. Under such hostile conditions, it is difficult for the equipment on-board the landers to function properly for any duration.

In comparison, Mars offers a clear view through its wispy atmosphere all the way down to its surface.

The launch window

The timing of the launch is a crucial decision controlled by several factors. An ideal launch date is one that requires the least amount of propellant (i.e., rocket fuel) to insert the spacecraft into the planned trajectory. Fuel adds to the weight of the whole mission, and fuel is also expensive.

The direction of launch is an important factor impacting fuel costs. We may naively think that the most efficient way to get to outer space is to launch the rocket directly up from Earth. But a straight line trajectory is a very inefficient way of spending energy.

Through its entire journey, the maximum fuel in a rocket is burned out at the very initial stages when the launch vehicle is trying to lift off and speed up away from the Earth's gravitational pull. A great deal of fuel can be conserved at this stage through certain choices.

1. Earth goes around the Sun at a speed of 100,000 kilometres per hour (about 30 km/s). If the launch vehicle can be accelerated in the same direction as Earth's revolution around the

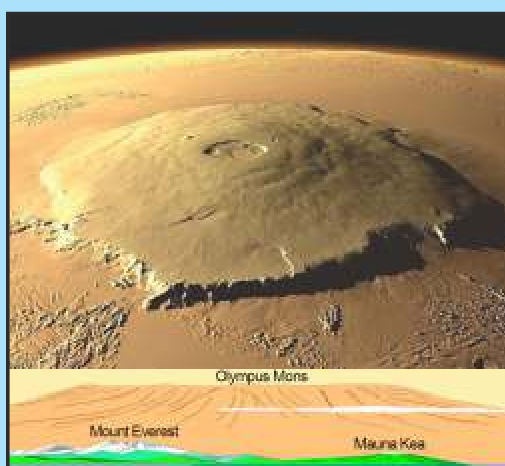
Other attractions on Mars

Global Dust Storms: Satellite and telescope observations have shown that large-scale dust storms are a recurring feature on Mars. They develop in a matter of hours and can cover the entire planet in a matter of a few days. Once these dust storms form, because of the low surface gravity of the planet, it takes several weeks for the dust to settle back on the ground. It is not clear, despite a very wispy atmosphere, why the storms become so large or why they last so long on Mars.

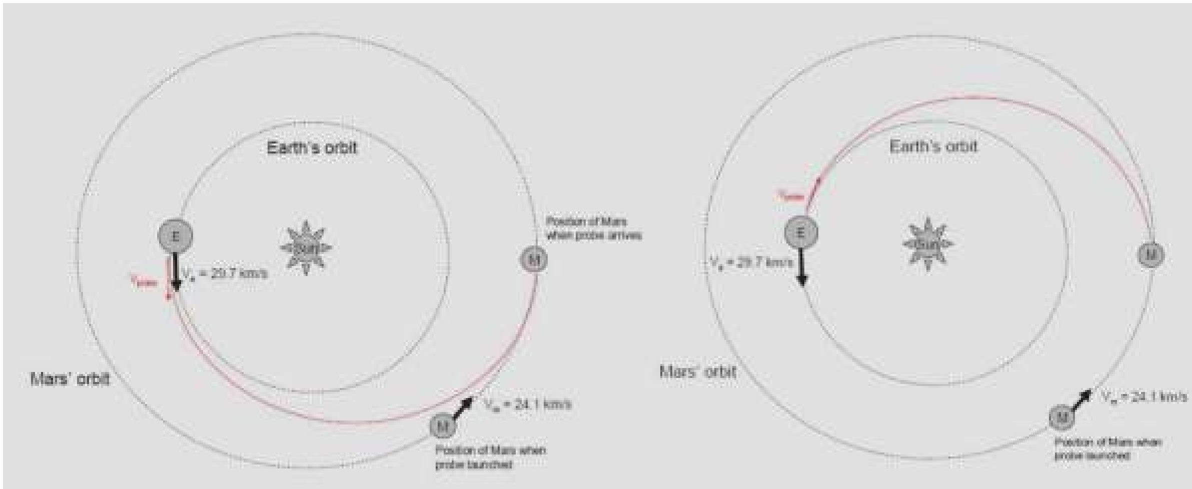
Great Canyons: The largest canyon in the solar system is on Mars. Called the Mariner Valley (after the Mariner 9 spacecraft that discovered this valley), this gigantic gorge that runs across the equator of Mars is about 4000 kilometres long, as long as the continent of Asia. This gorge shows many signs of past flooding, including deep channels carved by what could have been water that once gushed from above the chasm.

Mars_Mariner_Valley & Mars_Mariner_Valley_artist: The rift region seen along the equator of Mars is the Mariner Valley, the largest canyon in the solar system. The next image is an artist's impression of the Mariner Valley. Credit: NASA

Volcanic Mountains: Mars also has the distinction of having the largest known mountain in the solar system. Standing tall with a summit altitude of 22 kilometres and with a base girth of nearly 600 kilometres, Mount Olympus is three times bigger than Mount Everest, the tallest peak on Earth. Mount Olympus is also the tallest among a large number of extinct volcanic mountains on Mars. In addition to these, Mars also has a shield volcano called Olympus Mons. Rather than violently throwing up molten ash and lava, shield volcanoes are created by molten material slowly flowing down their sides.



Mars_Mount_Olympus_1: Mount Olympus, the tallest peak in the solar system, is on Mars. This photograph taken by one of the NASA satellites gives a close-up view of this now extinct volcanic mountain. Credit: NASA



Sun, it will give the vehicle a big head start in velocity (just as while jumping off a moving vehicle, we continue to run for some distance in the same direction with some speed).

2. Earth rotates from west to east on its axis. At the equator, Earth's surface is rotating at 1600 kilometres per hour. From an equatorial launching station, if we launch the rocket towards the east, it will get another enhancement in velocity from Earth's rotation.

Thus by launching in the same direction as the Earth's spin and its revolution around the Sun, the launch vehicle can take maximum advantage of these while trying to raise its altitude.

The launch vehicle and MOM payloads

Every satellite or spacecraft requires a launch vehicle, to propel and position the spacecraft into the desired orbit. The launch vehicles are usually unmanned rockets. The Mars Orbiter Mission was launched on the Polar Satellite Launch Vehicle (PSLV). PSLV has four stages to it with propellants that operate at different stages of the flight. The satellite is referred to as the *payload.* In PSLV, the payload is attached to the fourth and the final stage of the rocket (see photograph).

The satellite is enclosed in a heat shield, a protective layer of several materials split into two halves that come together. The heat shield has thermal and acoustic absorption layers padded inside. As the rocket picks up momentum, the parts of the rocket that come into direct contact with the Earth's atmosphere get heated up to several thousands of degrees from friction with the Earth's atmosphere. The shield insulates the satellite from this aerodynamic heating.

Each stage of the rocket burns out, separates and falls off at different times during the rocket's flight. The heat shield with the payload inside is the last to separate from the fourth stage of the PSLV rocket. This separation typically happens about 3 minutes into the flight, when the rocket has climbed to an altitude of 130 kilometres.

Photograph of PSLV-C25, the rocket that carried Mars Orbiter Mission. The rocket has a height of 45 m, a diameter of 3 meters and weighs approximately 300 tonnes. The rocket can deliver payloads of up to 1500 kg weight into geosynchronous orbit. © *ISRO*

Mars Orbiter Mission Spacecraft (covered in gold foil) attached to the 4th stage of PSLV-C25 and ready for heat shield closure. © *ISRO*

The Mars Orbiter Mission has five scientific instruments on-board. These five instruments cover three broad science themes all linked to forge a better understanding of the climate and geology of Mars. The payload instruments and their science objectives are as shown in the table.

1. The Lyman Alpha Photometer, referred to shortly as LAP, has a detector that can sense ultraviolet photons. The instrument has the capability to measure the current deuterium to hydrogen abundance ratio in the Martian atmosphere. This measurement will provide an estimate of how fast Mars is losing its atmosphere.

2. The Martian Exospheric Neutral Composition Analyzer, also called MENCA, is a mass spectrometer equipment that can measure the masses of different molecules in the Martian atmosphere and also analyze the atmosphere's chemical composition.

3. A Methane Sensor for Mars is an instrument to search for the presence of methane molecules in the Martian atmosphere down to concentration levels as low as one part in a billion molecules. Finding methane on Mars could signal the existence of microbial life. A significant fraction of methane on Earth is of biological origin. Certain micro-organisms, called methanogens, produce methane as a result of their metabolism. A similar biotic origin for methane is possible on Mars, if it supports microbial life.

4. A Mars Colour Camera is a 2000 x 2000 pixel array camera that can take high resolution images of the Martian surface at the same energies as normally visible to the human eye. With the camera images, one will be able to see shapes and features on Mars down to a distance scale of 25 kilometres.

5. The Thermal Infrared Imaging Spectrometer's purpose is to map the minerals on Martian surface. It does this by capturing thermal radiation (i.e., heat) emitted by the Martian surface heated by sunlight. The infrared light entering the spectrometer is separated into tiny portions of photon energies and an image is captured at each of those energies.

Conclusion

Mars exploration is an on-going saga. Even as you read this, a cluster of orbiters and robotic rovers are surveying Mars, providing detailed information on Mars's atmosphere, its climate, topography and soil composition, all the while continuing to search for the presence of water and microbial life. Since September 2014, MOM has joined this collective effort.

Of all the planets and minor bodies of the solar system, Earth is the only one that is presently known to harbour life. The process of how our planet evolved into such a safe haven for life is not yet fully understood. An answer to this is likely to come from probing planets like Mars that were once habitable worlds, but have gradually evolved away from it.

To read a great deal more on Mars, visit:
http://mars.nasa.gov/allaboutmars/

Types of interplanetary missions

Interplanetary space-crafts come within one or more of the following three categories: (a) Flyby space-crafts (b) Orbiters (c) Landers

(a) Flyby space-crafts: are missions that follow an escape trajectory, never to be captured into any planetary orbit. The only opportunity to gather data is when they fly past the objects of interest. Their advantage is that the same spacecraft can be used to acquire information on more than one object (planets, moons, asteroids etc) as long as the spacecraft's trajectory brings it close to the object. The early interplanetary missions were primarily flybys. Voyager 1, 2; Mariner 1 – 10; Pioneer 10 & 11 are all examples.

(b) Orbiters: are space-crafts that enter into an orbit around planets or moons of planets. Many of the later year Mars missions like Mars Global Surveyor, Mars Odyssey, MAVEN all fall in the category of orbiters. ISRO's Chandrayaan and Mars Orbiter Mission belong to this class.

(c) Landers: are space-crafts which are designed to land on the surface of a planet. Landers are often equipped with cameras to take surface level photographs of the terrain. They also have instruments to carry out in-situ experiments by extracting samples of soil or rock from the surface of the planet. An extension of a lander is a rover, a robotic spacecraft designed to move around and survey a larger area of the planet. Landers are typically deployed from an orbiter. Classic examples are the twin rovers Spirit and Opportunity.

History of Mars exploration

Human explorations of Mars started way back in the 1960s. In the ten years between 1960 and 1970, there were 12 attempts from the then Soviet Russia and the United States of America. After successive failures, on November 1964, the US spacecraft Mariner 4 became the first spacecraft to successfully flyby Mars.

Since then, these explorations have been a mix of triumphs and let-downs. The following tables offer a timeline summary of the history of Mars explorations. *(Data courtesy: Kiran Mohan, Liquid Propulsion Systems Centre, ISRO)*

Decade	No of Attempts	No of Success/Partial Success	No of Failures
1960s	12	3	9
1970s	11	6 (including 1st orbiter)	5
1980s	2	1	1
1990s	8	3	5
2000s	8	7	1
2010s	3	1	2
Total	**44**	**21 (47%)**	**23(53%)**

1960 – 1970

Mission	Country	Date of Launch	Mission Type	Status
Mars 1M No.1	USSR	10 Oct 1960	Flyby	Launch Failure
Mars 1M No.2	USSR	14 Oct 1960	Flyby	Launch Failure
Mars 2MV-4 No.1	USSR	24 Oct 1960	Flyby	Launch Failure
Mars 1	USSR	1 Nov 1960	Flyby	Some data collected. Lost contact before reaching Mars, flyby at approx. 1,93,000 km
Mars 2MV-3 No.1	USSR	4 Nov 1960	Lander	Failed to leave Earth's orbit

Mission	Country	Date of Launch	Mission Type	Status
Mariner 3	USA	5 Nov 1964	Flyby	Failure during launch disrupted trajectory
Mariner 4	USA	28 Nov 1964	Flyby	Success
Zond 2	USSR	30 Nov 1964	Flyby	Communication lost before Mars transfer
Mariner 6	USA	25 Feb 1969	Flyby	Success
Mariner 7	USA	27 Mar 1969	Flyby	Success
Mars 2M No.521	USSR	27 Mar 1969	Orbiter	Launch Failure
Mars 2M No.522	USSR	2 April 1969	Orbiter	Launch Failure

1970 – 1980

Mission	Country	Date of Launch	Mission Type	Status
Mariner 8	USA	8 May 1971	Orbiter	Launch Failure
Kosmos 419	USSR	10 May 1971	Orbiter	Launch Failure
Mars 2	USSR	19 May 1971	Orbiter, Lander, Rover	Orbiter-Success (27/11/1971) Lander & Rover Crashed on to Mars Surface
Mars 3	USSR	28 May 1971	Orbiter, Lander, Rover	Orbiter-Success (2/12/1971) Lander & Rover partial success as it soft landed, but transmission lost within 15 minutes (First Successful touch down)
Mariner 9	USA	30 May 1971	Orbiter	Success (first successful Orbiter 13/11/1971)
Mars 4	USSR	21 July 1973	Orbiter	Close Flyby only
Mars 5	USSR	25 July 1973	Orbiter	Partial Success Entered Orbit but failed within 9 days
Mars 6	USSR	5 August 1973	Lander	Partial success. Data returned during descent but not after landing on Mars
Mars 7	USSR	9 Aug 1973	Lander	Landing probe separated prematurely; entered a Sun centered orbit. Failure
Viking 1	USA	20 Aug 1975	Orbiter, Lander	Success
Viking 2	USA	9 Sep 1975	Orbiter, Lander	Success

1980 – 1990

Mission	Country	Date of Launch	Mission Type	Status
Phobos 1	USSR	7 July 1988	Orbiter, Lander	Contact Lost during transfer orbit
Phobos 2	USSR	10 July 1988	Orbiter, Landers	Orbiter Successfully entered orbit and returned data. Lost contact just before deploying landers

1990 – 2000

Mission	Country	Date of Launch	Mission Type	Status
Mars Observer	USA	25 Sep 1992	Orbiter	Lost contact before arrival on Mars
Mars Global Surveyor	USA	7 Nov 1996	Orbiter	Success
Mars 96	USA	16 Nov 1996	Orbiter, Lander, Penetrator	Launch Failure
Mars Pathfinder	USA	4 Dec 1996	Lander, Rover	Success (First successful Rover)
Nozomi (Planet-B)	Japan	3 July 1998	Orbiter	Never Entered Orbit
Mars Climate Orbiter	USA	11 Dec 1998	Orbiter	Crashed on surface. Error in the computer program used for correction thrusters
Mars Polar Lander	USA	3 Jan 1999	Lander	Crash landed on surface
Deep Space 2	USA	3 Jan 1999	Hard Landers	Crash landed on surface

2000 – 2010

Mission	Country	Date of Launch	Mission Type	Status
2001 Mars Odyssey	USA	7 April 2001	Orbiter	Success
Mars Express / Beagle 2	ESA	2 June 2003	Orbiter, Lander	Orbiter Success, Landing failure for Lander
MER-A Spirit	USA	10 June 2003	Rover	Success
MER-B Opportunity	USA	7 July 2003	Rover	Success
Rosetta	ESA	2 March 2004	Gravity assist to comet	Success
Mars Reconnaissance Orbiter	USA	12 Aug 2005	Orbiter	Success
Phoenix	USA	4 Aug 2007	Lander	Success
Dawn	USA	7 July 2003	Gravity assist to Vesta	Success

2010 – Till Now

Mission	Country	Date of Launch	Mission Type	Status
Fobos-Grunt	Russia	8 Nov 2011	Lander, Sample Return	Failed to leave Earth orbit. Fell back to Earth
Yinghuo-1	China	8 Nov 2011	Orbiter	Failed to leave Earth orbit. Fell back to Earth
Curiosity	USA	26 Nov 2011	Rover	Success
Mars Orbiter Mission	India	5 Nov 2013	Orbiter	Success
MAVEN	USA	18 Nov 2013	Orbiter	Success

Further reading

1. http://www.isro.gov.in/pslv-c25-mars-orbiter-mission - For details on the orbiter mission, the launch vehicle, ground segment operation, and plenty of images from the preparatory stages of the mission.
2. http://mars.nasa.gov/ - for details on the planet and the history of Mars exploration by NASA.
3. http://www.marsquestonline.org/ - for a variety of multimedia based learning activities on Mars suitable for school students.
4. http://phoenix.lpl.arizona.edu/mars101.php - the NASA Phoenix mission site has a detailed write-up on the search for water on Mars and the possibility of finding life.
5. http://www.jpl.nasa.gov/news/news.php?release=2012-305 - on Curiosity finding evidence water on Mars, finding ancient streambed gravels

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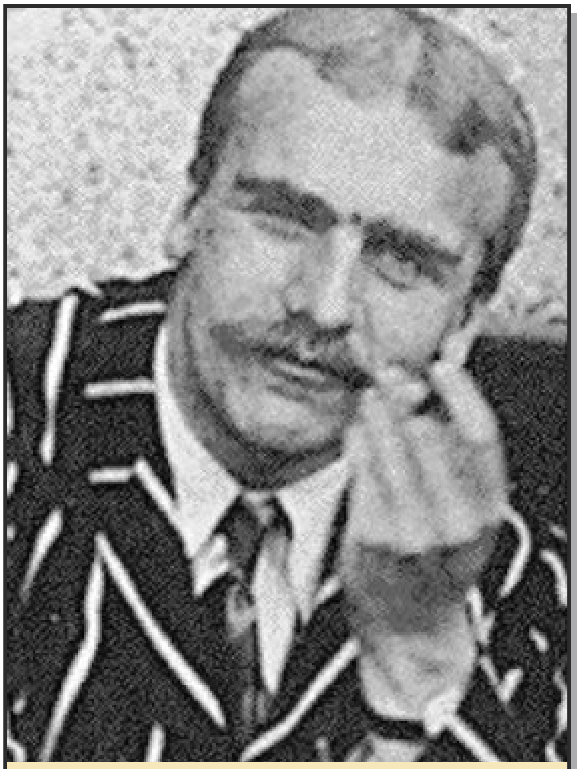
J. B. S. HALDANE

A "GREAT RASCAL OF SCIENCE"

T V Venkateswaran

What made J.B.S. Haldane one of the most respected scientists of the 20th century? At the same time, why was he called a 'great rascal of science'? What are his contributions to science and what kind of a person was he? This article takes us through the remarkable life of one of the most interesting and accomplished scientists of the 20th century.



J.B.S. Haldane, in Oxford UK, 1914.
Source: Public domain. Image downloaded from http://students.washington.edu/gw0/modernsynthesis/images/haldane.png and converted to JPG
Original uploader was Bunzil at en.wikipedia.

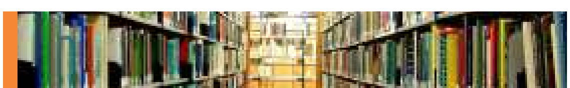
Working under intense pressure

It was the 1940s. The world was in the grip of the Second World War. This was no ordinary war. The amassed armies on both sides faced a new generation of weapons, from barbed wire, to rapid fire artillery, to machine guns that spat out 600 rounds a minute – all these changed the very nature of war. Soldiers from all sides slaughtered each other, and the war ravages shattered the very foundations of civilisation. Air raids and submarines were bringing the war to every door step, and for the first time in history, the civilian casualties were far more than the death of uniformed soldiers.

British and allied submarines were facing the dangers of German attack underwater. When a submarine is hit by a mine, the men inside it had no option but to dive out and swim to the surface. Often, they used diving equipment to breathe as they ascended from the depths of the ocean. But, all was not well with these diving equipments. There were many fatalities that resulted from causes ranging from nitrogen narcosis (consequent from increase in the partial pressure of nitrogen) to carbon dioxide poisoning. Oxygen, otherwise necessary for human life, became life threatening under water. Divers were advised not to breathe pure oxygen, and were instructed to

watch out for symptoms of oxygen poisoning; tingling of fingers and toes, twitching of muscles, convulsions followed by unconsciousness, and death.

A rigorous understanding of oxygen toxicity, human limits, and suitable gas mixtures for oxygen tanks, was clearly needed. One man was given the task of tackling these physiological dangers to which divers and other men, trying to escape from submarines, were exposed. That man willingly subjected himself to entering pressure chambers with varied gas mixtures in an effort to discover the true resiliency and limitations of humans when living a "Life Under Pressure", and in the process almost died. He found that exposure to pure oxygen at severe atmospheric pressure led to convulsions within 5 minutes, and helped develop an ideal nitrogen - oxygen mixture, which lowered the risk of both oxygen toxicity and nitrogen narcosis (an alteration in consciousness that occurs while diving at depth). These pioneering studies not only helped save many lives during the war; but also led to the development of safe scuba diving equipment, making it possible for humans to explore the depths of oceans.



Some important books written by J B S Haldane:

1. Daedalus; or, Science and the Future (1924)
2. Possible Worlds and Other Essays
3. The Inequality of Man, and Other Essays (1932)
4. Science and the Supernatural: Correspondence with Arnold Lunn (1935), Sheed & Ward, Inc.
5. Marxist Philosophy and the Sciences (1939)
6. My Friend Mr. Leakey (1937)
7. Everything Has a History (1951)

(The last two books are available as eBooks in Vigyan Prasar Digital library, for free download. See www.vigyanprasar.gov.in).

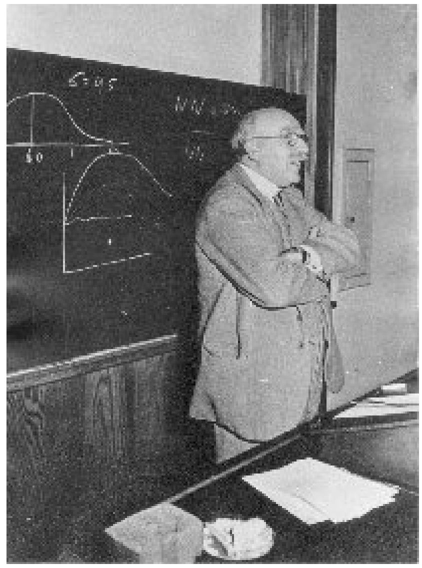
The allrounder

That eccentric man was J.B.S. (John Burdon Sanderson) Haldane, a famous British geneticist and evolutionary biologist, and one of the greatest scientists of the 20th century. A gifted mathematician, biologist, socialist, atheist, materialist and superb populariser of science, Haldane was acclaimed as a genius. From human philology to population genetics, his works continue to stimulate and interest scholars. He was the first to suggest in vitro fertilisation ("test tube babies"). Many scientific terms, such as cis, trans, coupling, repulsion, and darwin (as a unit of evolution) were coined by him; and he was the first to use the term "clone", to describe the possibility of creating exact copies of animals. Noting that fossil fuels, like coal, would not last forever, he was also the first to suggest hydrogen-powered renewable sources of energy.

J.B.S. Haldane was born in Oxford, England, on November 5, 1892, to a family of Scottish aristocrats. About his childhood he wrote, "...as a child I was not brought up in tenets of any religion, but in a household where science and philosophy took the place of faith. As a boy I had very free access to contemporary thought, so that I do not today find Einstein unintelligible, or Freud shocking". No wonder then, that he got admission to Eton, and later Oxford, for pursuing higher studies, where from he graduated in 1914 with a MA degree in mathematics, classics and philosophy. From 1914 to 1919, he served as a military officer in World War I. Haldane became a Reader in Biochemistry at Cambridge University (1922-32), and the Professor of Genetics at London University (1933-37). In 1930, he became a Fullerian Professor of Physiology at the Royal Institution, London.

Although he studied mathematics, his interest in genetics was kindled, when he attended a lecture on Mendel's genetic principles in 1901. It was during this time that Mendel's laws were rediscovered, and were considered to be contrary to Darwin's theory of evolution. Haldane, together with R. A. Fisher and Sewell Wright, not only showed that both the theories were compatible, but also developed the theory of population genetics, which still underpins all serious thinking about evolution. In 1912, he published his first paper on genetic linkage, following it with research on the genetics of haemophilia and colour blindness. His book 'The Causes of Evolution' was a landmark in population genetics. Among many scientific firsts, he investigated the

biochemistry of gene action, the genetic control of enzyme reactions, calculated mutation rates for genes, created linkage maps for human chromosomes, and analysed human pedigrees to understand different modes of inheritance. While at Cambridge (1922- 33), he formulated a mathematical model of natural selection.



Through his study of enzymes, and using some elegant mathematics, he calculated the rates at which enzyme reactions take place, and showed (in collaboration with G.E. Brigs) that enzyme reactions obey the laws of thermodynamics. Haldane's work on regulation of blood alkalinity is basic textbook material. Haldane and A.I. Operin independently suggested a plausible mechanism for the origin of life in an anaerobic pre-biotic world.

The socialist

Haldane was not only a flamboyant and productive scientist, but also had deep humanist commitments. As a compassionate humanitarian, J.B.S. Haldane was distressed at the rising unemployment, destitution and squalor all around. During World War I, he became a socialist. In the 1930s, he began reading the work of Vladimir Lenin, becoming a supporter of Marxism, and joining the British Communist Party in 1942. His work "The Marxist Philosophy and the Sciences (1938)", and his preface to the English edition of Engels's "Dialectics of Nature", are considered classics. Haldane wrote, "Had his (Engels) remarks on Darwinism been greatly known, I for one would have been saved a certain amount of muddled thinking". He left the party during the 1950s, but maintained a Marxist philosophy throughout his life.

Haldane stressed on the social responsibilities of science and scientists, and argued that it is the duty of a scientist to render science intelligible to ordinary people. He wrote volumes of essays explaining science to ordinary people. He accepted the position of Chairman of the editorial board of the left-wing 'Daily Worker', wherein he wrote more than 300 articles on scientific themes, often mixed with political comments, conveying complex concepts with clarity and humour.

Some of his popular essays were published in the anthology, Possible Worlds (1927). In the essay "On Being One's Own Rabbit," he describes the experience of running tests on himself in lab experiments. Noting the clarity one gets from mathematics he said "An ounce of algebra is worth a ton of verbal argument". Elsewhere (Fact and Faith 1934), he wrote "my practice as a scientist is atheistic. That is to say, when I set up an experiment I assume that no god, angel, or devil is going to interfere with its course; and this assumption has been justified by such success as I have achieved in my professional career. I should therefore be intellectually dishonest if I were not also atheistic in the affairs of the world". He argued that "the main objection to religious myths is that, once made, they are so difficult to destroy. Chemistry is not haunted by the phlogiston theory as Christianity is haunted by the theory of a God with a craving for bloody sacrifices. ....Chemists believe that when a chemical reaction occurs, the weight of the reactants is unchanged. If this is not very nearly true, most of chemical theory is nonsense. But experiments are constantly being made to disprove it. It obviously cannot be proved, for, however accurately we weigh, the error may still be too small for us to observe. Chemists welcome such experiments and do not regard them as impious or even futile".

The right size

"On Being the Right Size", published in 1928, is one of Haldane's most appreciated essays. In it, he asks why mice are small and whales are big. More generally, he asks, is size an accident, or is there a good reason? "You can drop a mouse down a thousand-yard mine shaft; and on arriving at the bottom, it gets a slight shock and walks away. A rat would probably be killed, though it can fall safely from the eleventh story of a building; a man is killed, a horse splashes." Why aren't there any giant insects? He wrote "Insects don't have lungs. Instead, they have a system of holes and tubes that allow oxygen to reach the cells inside their bodies. But this passive system doesn't work for anything much larger than the size of today's

Galileo, in his book, 'Dialogues Concerning Two New Sciences', noted this, and explained why objects cannot have arbitrary sizes. When an object is scaled up, its area increases only by the square of the multiplier, while the volume increases by the cube of the multiplier. Thus, for example, if there are two cubes A & B, such that each of the sides of B is ten times that of corresponding sides of A, then, while the surface area of B will only be 100 times that of A, its volume will be 1000 times that of A.

insects. They've gotten about as big as they can, and we can sleep without fear that a two-hundred pound ant will someday come crashing through the door". In Haldane's words, "The higher animals are not larger than the lower because they are more complicated. They are more complicated because they are larger". Further, Haldane explains why birds are the size of birds, why small animals can't live in frozen regions, and why large animals don't have enormous eyes. Many of his examples in this book are based on the **square-cube law**, although he does not use that terminology.

Serving science-in life and death

At the age of 65, in 1957, Haldane and his wife, Helen Spurway (an accomplished geneticist herself), were disturbed at the imperialist Suez invasion of Anglo-French forces, and in protest they immigrated to India. Initially he joined Indian Statistical Institute (ISI), Calcutta, at the invitation of P.C. Mahalanobis, and subsequently established an Institute for Biology and Genetics, at Bhubaneswar. Haldane had a deep appreciation of Indian culture, was deeply engrossed in Indian Philosophy, and had a good knowledge of Sanskrit. In April 1961, he became an Indian citizen. He attended international science conferences sporting a kurta and pyjama, identifying with independent India; and invited scientists across the world to collaborate with developing countries.

Like life, he faced his death with wit and bravery. He wrote "I am a part of nature, and, like other natural objects, from a lightning flash to a mountain range, I shall last out my time and then finish. This prospect does not worry me, because some of my work will not die when I do so". Afflicted with cancer, lying in the hospital bed, he wrote an outrageous comic poem, mocking his own incurable disease:

"... I know that cancer often kills,
But so do cars and sleeping pills;
And it can hurt one till one sweats,
So can bad teeth and unpaid debts.
A spot of laughter, I am sure,
Often accelerates one's cure;
So let us patients do our bit
To help the surgeons make us fit."

He passed away on December 1, 1964. As per his will, his body was sent to the Rangaraya Medical College, Kakinada for scientific use. "My body has been used for both purposes during my lifetime", Haldane wrote in his will, "and after my death, whether I continue to exist or not, I shall have no further use for it, and desire that it shall be used by others". No wonder that Richard Milner, aptly, said "J. B. S. Haldane was one of the great rascals of science; independent, nasty, brilliant, funny and totally one of a kind".

***T V Venkateswaran**, Scientist with Vigyan Prasar, Department of Science and Technology, New Delhi, is a prolific science writer with more than 25 popular science books and 300 science articles to his credit. He conducts science TV shows, resource person for training programmes, and writes for periodicals. His research interest includes history of popular science in Tamil, and in particular the modern Indian astronomer Chintamani Ragoonathacharry. Says that he is lucky to have his passion as his vocation - he could read books, watch movies and interact with children, teachers - call it 'work' and get paid for it! He likes to travel, listen to Carnatic music and cook exotic dishes. One of his secret vices is to read spy thrillers and detective novels. The author can be contacted at tvv123@gmail.com.*

OBSERVING LIGHT:

SHADOWS AND REFLECTIONS

Rajaram Nityananda

Are shadows completely dark? Are there some shadows that are darker than others? What do a mobile phone camera and the human eye have in common? Are there any natural pin-hole cameras? How many mirrors do we need to see our right hand appear as it would to others? In this article, the author explores many simple ways in which the teaching of light can link everyday observations to concepts using shadows and reflections.

Introduction

It is always a challenge to build curiosity, motivation, and a basic understanding of any topic in science. A popular trend worldwide is to bring in technology – computer animations and demonstrations, with specially designed equipment. This trend attempts to overcome the sense of familiarity and boredom, which comes with early exposure to mass media and the internet, and is now catching on in our own schools in India.

There is no doubt that technology has value in creating interesting learning experiences. But this article is about the oldest technology – live, (meaning not virtual) observation. Simple observations are not meant to be a second best option, that one engages with because of a lack of online or lab resources. They are valuable even to students who have access to virtual resources, because, ultimately, science is about the real world. First hand experiences can help a student connect to the more abstract developments, which school science must cover in later years. Without such a connection, even students who do well in existing school systems may find it difficult to apply what they learn from books and lectures to new situations. Even if one first learns the theory, it really helps to see it being put into practice and use observation to build connections. The observations suggested here are not just for students in middle school, but for anyone, teachers included, who has not tried them!

Light appears early in the school science curriculum. This is natural - vision is one of our most powerful senses. Studying light is an opportunity for teachers to enthuse students about science, by relating it to observations that they can themselves make and think about. This article covers two basic topics, shadows and reflections. These occur in all textbooks, with the usual ray diagrams showing light travelling in straight lines from the source. This is already a virtual experience – students do not always connect the figures with what they see, but know that the diagrams have to be reproduced in tests and interviews.

Shadows: not completely dark!

One way to think about the shadow of an object – say a duster – is to imagine that a small creature, say an ant, sits on a wall. Take a look at the image below to understand the positions of the Sun, the duster and the ant. We can ask what the ant would

see if it were at different positions with respect to the duster and the Sun. If a point on the wall is dark, it means that the ant sitting there finds that the Sun is completely blocked by the object. As we move it away from this point on the wall, we notice that the edge of the shadow of the duster is not sharp. This observation is what illustrates the, so-called, penumbra. ‘Penumbra’ is just a name! Isn’t it better to say that as the ant crawls past the edge of the shadow of the duster, it moves from the region where the Sun is completely covered, to one where it is partially covered (the penumbra) and finally to one from where it can see the entire Sun? (It is wise to imagine this, rather than actually going under such a shadow and looking at the Sun oneself – looking directly at the Sun can damage the eye.)

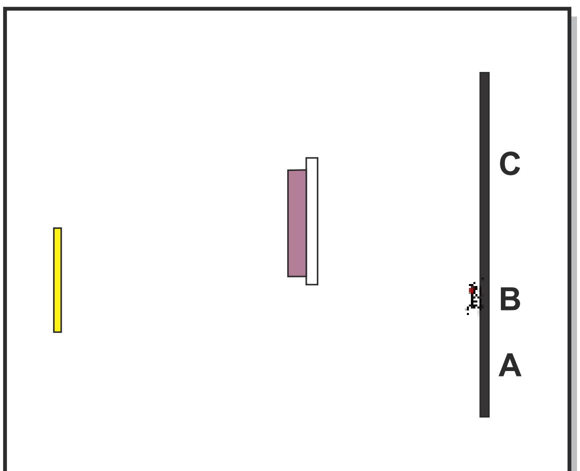


Figure 1: The yellow line on the left represents the Sun. The ant on the wall at C cannot see any part of the Sun. The ant at A can see the whole Sun. The ant at B can see part of the Sun. It lies between the darkest part and the fully lighted part. This is the fuzzy edge of the shadow.

The next experiment surprises even practicing scientists. Hold two pencils in the sunshine, at a time near noon, so that the shadows fall on the ground more than a metre from the pencils. By moving one pencil over the other, one can make the shadows overlap, and then again come apart. Surprisingly, the shadow is darker just before and just after the overlap, and becomes brighter when there is a full overlap! One can also hold the pencils crossed, in which case the darkest portion of the shadow is not at the intersection, but on either side. This is explained in Figure 2, from the point of view of an ant on the ground. So, this is actually a useful way of thinking about shadows!

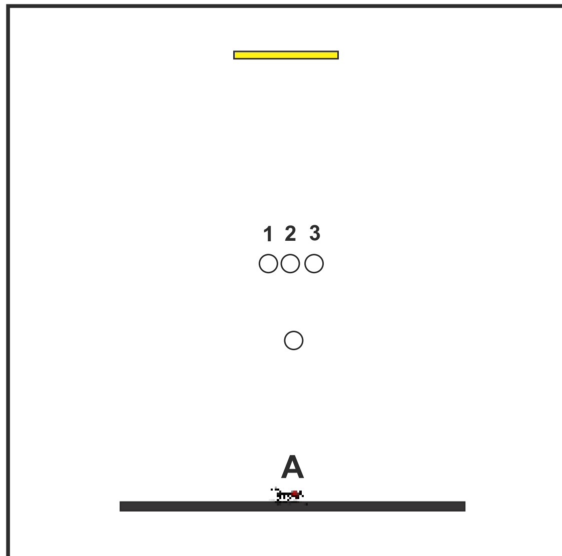


Figure 2: Overlapping the shadows of 2 pencils. When the moving pencil on the left is at position 1 or 3, then the ant at A sees a larger part of the Sun covered. When it is at position 2, the pencils cover each other, and more of the Sun is visible. This explains the increase in light at A, when the shadows overlap.

What lies between the shadows?

Let us now look at the opposite of a shadow. When light passes through a hole in a piece of cardboard, we get a bright region inside the

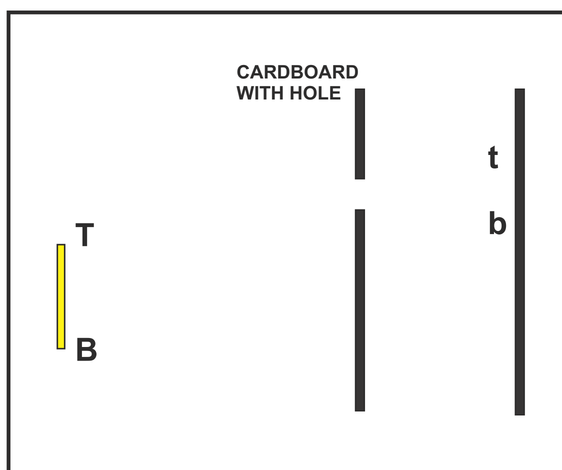


Figure 3: How a small hole in a piece of cardboard makes an inverted image of the Sun. The point t on the upper side of the wall receives light from B, the bottom of the Sun. The point b on the lower side of the wall receives light from T, the top of the Sun. This arrangement only works if the hole makes an angle smaller than that of the Sun as viewed from the wall. If the hole is very close to the wall, the lighted portion on the wall takes the shape of the hole.

shadow. We expect a square hole to give us a square patch of light, a triangular one to give a triangular patch, etc. This is what we see when we place the cardboard close to the wall. When the hole is small (say about 3 millimetres in size), something interesting happens as we move away from the wall. At a distance of about half a metre, the patch of light starts looking more circular; at a distance of about a metre, we see an almost circular disc; even though the hole may have been a triangle! What's more – the size of the bright patch starts increasing.

The circular patch is an image of the Sun. This observation is the basic principle behind a pinhole camera, shown in Figure 3.

Students can easily make this simple toy for themselves. This is also a good way of introducing the workings of the human eye, the basic tool for all our observations. The eye is a beautiful collector of light which shows the brightness and colour of light from each direction. This is what we call a picture or image. In fact, the camera in mobile phones, which many students will be familiar with, is more like the eye than earlier film-based cameras. It has a chip, which is like the retina, with wiring connecting the chip to a computer, pretty much like the optic nerves going to the brain! It also has software to make the upside down picture, right side up. Our brains seem to have this as well.

Figure 4a: Circular patches of light, which are images of the Sun made by natural pinholes (gaps between leaves) in the shade of a tree. Image courtesy http://nivea.psycho.univ-paris5.fr/FeelingSupplements/ExperimentsWithCameraObscura.htm

Actually, this pinhole experiment is carried out for us naturally, when we go and look at the shade of a tree. As Figure 4a shows, we often see circular patches of light. This happens even though the gaps between the leaves through which the Sun shines have irregular shapes. During a partial eclipse of the Sun, which can be seen from most places in India about once in every decade, the circles become crescents, making it clear that we really are seeing images. December 26th, 2019 is the next date on which a partial eclipse will be visible from India, and the next date following this one will be on June 21st, 2020 (monsoon clouds may spoil the view of this one). Figure 4b shows a spectacular set of shadows of the eclipse of May 20, 2012, visible from the US. In this case, the moon left a ring shaped part of the Sun visible!

Another interesting aspect of shadows is revealed when one looks at the moon through binoculars (even though moonlight is much weaker than sunlight, one should be careful of the glare). The picture of the full moon (in Figure 5a) does not show any shadows. The half-moon (in Figure 5b) however, shows clear shadows of mountains and craters. It is a more interesting picture, although poets have sung praises of the full moon. We all know that shadows are long when the Sun is low

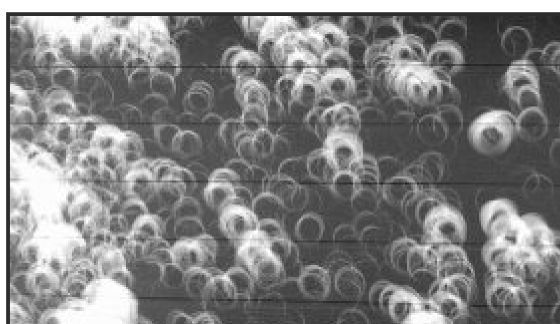


Figure 4b: Pinhole images of the Sun taken during the eclipse of May 20, 2012. Source: Image of the eclipsed Sun, taken from Carson City, Nevada. Photographer Dean Altus http://media.komonews.com/images/120521_eclipse_shadow_lg.jpg

on the horizon, and disappear when the Sun is overhead. So it is not surprising that we don't see shadows near the centre of the full moon. If one were sitting there, the Sun would be overhead. Near the edge of the full moon, the mountains do cast shadows. But these are invisible from the same direction as the Sun! At half moon, this problem is not there, and the shadows are plain for us to see.

Figure 5a: A photo of the full moon. Notice that we don't see any shadows even though there are mountains and valleys. Acknowledgment: "FullMoon2010" by Gregory H. Revera - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:FullMoon2010.jpg#/media/File:FullMoon2010.jpg

Figure 5b: A picture of the half moon. Note the clear shadows near the boundary between the lighted and dark part. An observer located there would see the Sun close to the horizon and hence shadows would be long. Acknowledgment: "Lune nb" by I, Luc Viatour. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Lune_nb.jpg#/media/File:Lune_nb.jpg

These are just some examples involving shadows, which can be used to provoke observation and discussion. Such examples are not meant to replace the textbook and classroom teaching, but, rather to create some enthusiasm to understand taught concepts. In higher classes, these experiments can help one appreciate how simple, but general, concepts, like rays of light, enable us to understand so many things around us.

Doing it with mirrors

We now turn to mirrors, which fascinate most children, until they grow up and start taking them for granted. Most of us are aware that a mirror shows us a person whose left hand is like our right hand. The unfortunate name, 'lateral inversion', is given to this change. This is unfortunate, because, actually, what is reversed in the mirror is the direction in which the person is looking! The other two directions remain the same. For example, our top and bottom are not interchanged. Our languages define left and right with respect to the direction in which a person is looking, but define top and bottom with respect to the earth. This is not just a point of language, but can be a matter of life and death. A surgeon operating on a patient should definitely be clear when saying "left" - does this mean the patients left, or the surgeons own?!

It is true that a single mirror does not show us as we appear to others. This is particularly clear to a person wearing a garment, like a sari, which goes over one shoulder; or shirts, which have pockets on one side. To see yourself as others see you, use two mirrors, placed at 90 degrees to each other. If you have not looked into such a set up before, it can be a strange experience. As you move your right hand away from you, the image also moves its right hand away from itself! A simple way of understanding this is given in Figure 6.

Even stranger is the experience when one looks into three mirrors, each placed at 90 degrees to the other two. The geometry of this would be like two walls and the floor meeting at the corner of a room. It is therefore called a 'corner reflector'. Any ray of light, coming from any direction, into the corner reflector, is sent back in the same direction (Figure 7a). What does one see when one looks into such an arrangement? No matter where one goes, one sees one's own eye in the corner!

This is not just a curious trick, but actually also very useful. Such reflectors are used on highways, especially near the edge of a dangerous curve. At night, the headlights of an approaching car

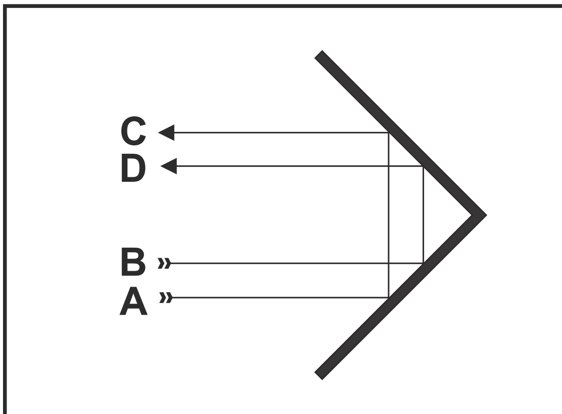


Figure 6: Reflection from a pair of mirrors making an angle of 90 degrees with each other. As the person standing in front of the mirror moves the right hand from B to A, the hand of the reflected image which is on the opposite side moves from C to D. This means that it is also seen as a right hand moving away. With a single mirror, the image would appear to move the left hand in the same direction.

illuminate the reflector, and it sends light back to the driver as a warning. This is a very efficient arrangement. It needs no power, and only sends light where it is needed. A more dramatic example is of a corner reflector, set up by American astronauts on the moon during the Apollo mission (Figure 7b). Using this, scientists were able to send a beam of laser light to the moon from a telescope on earth, and get the returning beam back, at the same telescope. Because the light was a short pulse, they were able to measure

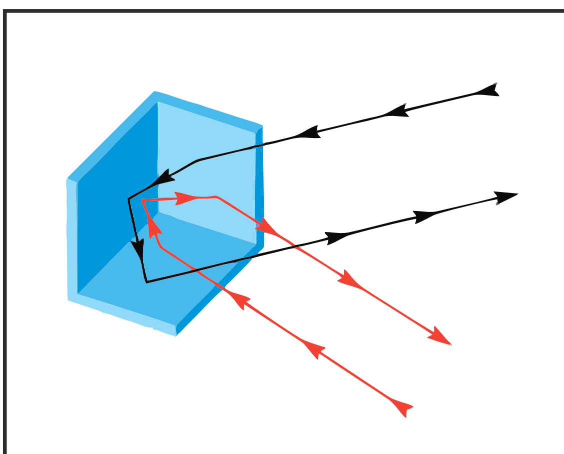


Figure 7a: An arrangement of three mirrors meeting at a corner. Light coming from any direction is sent back in the same direction.
Acknowledgment:
http://en.wikipedia.org/wiki/Corner_reflector#/media/File:Corner_reflector.svg

the time taken (about 2.5 seconds) and, hence, the distance to the moon, very accurately.

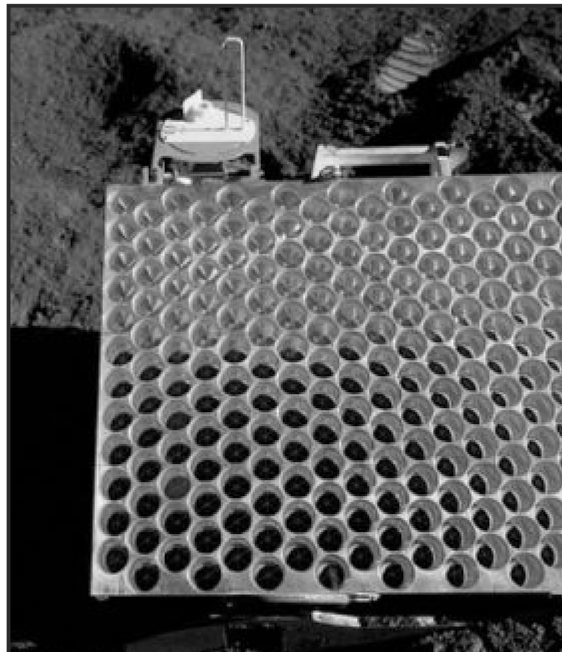


Figure 7b: A set of corner reflectors placed on the moon by astronauts on Apollo 15. This allowed very accurate measurements of the distance to the moon, and how it changes with time. Courtesy: NASA, USA

Nowadays there is great interest in using solar energy. One interesting method of using mirrors to bring sunlight from a large area to a small one, is shown in Figure 8.

Figure 8: A power plant in Spain, which uses energy from the Sun, instead of coal, to produce the steam that runs its generators. Because of the dust in the air, one can actually see the path of the Sun's rays. Acknowledgment:
http://en.wikipedia.org/wiki/PS10_solar_power_plant#/media/File:PS10_solar_power_tower.jpg

The last two examples show how a simple topic, like reflection, is important in today's space and energy technology.

Conclusion

Today's students will live in an age of far more advanced technology than their teachers. Many of these will involve light. That is why the United Nations has declared 2015 as the international year of light and light based technologies. Lasers are already used for cutting in industry. They are used by doctors to reshape the cornea of the eye to correct vision. Light carries most of our phone conversations and internet surfing over optical fibres. Many new, wonderful and useful things are bound to come of our understanding of light, in the future too. Those students, who make a career in science or engineering will learn much more about light. But everyone can, and should, appreciate some of the most basic principles of light, a few of which have been brought out in this article.

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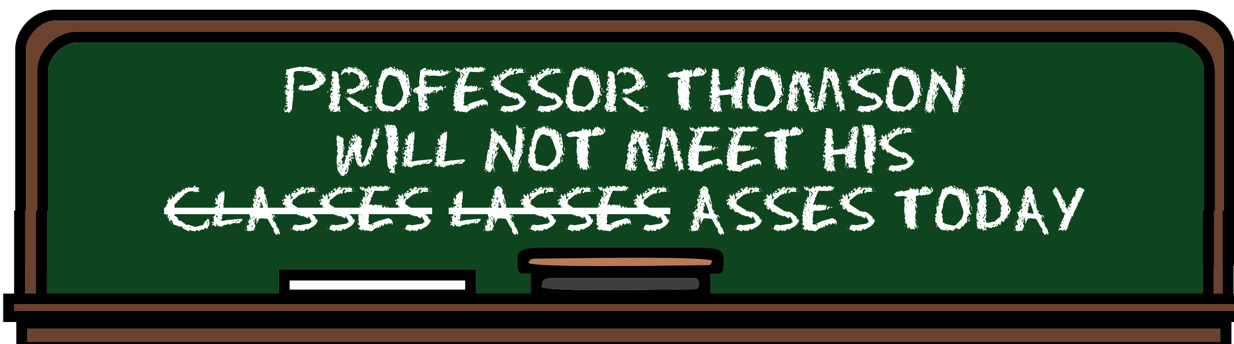
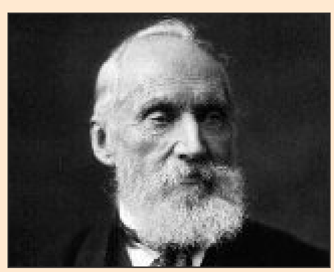


Sir William Thomson, a mathematical physicist and engineer, was a professor of Natural History (now called Sciences) at the University of Glasgow. He was an eccentric professor with a great sense of humour, full of drama and theatrics, and so, well admired by his students. Once when he could not take his lecture due to another commitment, he left a notice for his students on the lecture room door! "Professor Thomson will not meet his classes today".

A group of students decided



to have some fun at the professor's expense. They carefully erased the "c" from the note - "Professor Thomson will not meet his lasses today", and waited to see his reaction. When they returned to see the note, it read, "Professor Thomson will not meet his asses today"- the fun loving professor had erased the 'l'!

The eccentric Professor Thompson is none other than Lord Kelvin who was born as William Thompson, and later received the title Baron Kelvin of Largs. He was knighted by Queen Victoria for his Trans-Atlantic telegraph project. He was the electrical engineer responsible for laying the first successful transatlantic telegraph cable in 1866. Although he is also noted for his work on the mariner's compass, he is best known for his discovery of the Kelvin temperature scale.

Contributed by: Geetha Iyer. Source: Science Education Review,Vol 1, No.2-2002 (Robacker, cited in Folino, 2001)

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AN INTERVIEW WITH DR. SATISH KHURANA

This article in an interview with Dr. Satish Khurana, who is currently working as a Research Associate at University of Leuven, Belgium. His research interests include exploring intrinsic and extrinsic (HSC "niche") factors regulating hematopoietic stem cell (HSCs) function, HSC homing, proliferation and ageing. Before this, Dr. Khurana was completing his doctoral work, also on HSC's, from the National Institute of Immunology, New Delhi, India.

1. What sparked off your interest in science?

In many cases, it is hard to pick an event that moulds one's interest. I am not sure if I can put my finger on any event that happened in my life and made me interested in science. Actually, when I think of it, many events were contrary to it and threatened my stay in academics. Sometimes you are born with an interest or a bent of mind or a nature for which some things suit you and others don't. Science suits me and I just hope that I am suitable to do it. I was always interested in watching and observing things happen. When you think about it, stuff as simple as boiling and frying and floating and sinking, all involve science. If you try to understand why and how these happen, you are interested in science. I think interests are very natural and personal "fires", which burn without spark.

2. Could you tell us a couple of things that your school did that got you interested in science?

In my view, schools need to do a lot more to let students follow their own path. More often than not, teachers are not actually aware of the career (or even non-career) paths that can be taken in order to follow your interests or dreams. First, it is very important to have a curiculum to encourage independent thinking. Second, teachers have the responsibility to guide their students towards their goal. A huge proportion of Indian students might not have access to well trained teachers, who at best can guide them to conventional ways of earning livelihood. Although, research is more conventional than it used to be, students are still not really enthusiatic about it or aware of that path.

3. Tell us something about what you are working on currently.

I have been interested in Stem Cells (Stem cells are undifferentiated biological cells that can differentiate into specialized cells) and I started my PhD in order to understand how they function. My early days in research dealt with the problem of liver repair and the role of hematopoietic stem cells (HSCs; the cells that make blood cells, and live in the marrow of the bones) in this process. They are the best-known stem cells and have been in clinical use for a very long time now. By the end of my PhD, I developed interests in several related questions, the answers to which could be important in making better use of these stem cells in clinical practice. For instance, cord blood is a waste product when a child is born and it contains HSCs, which can be transplanted for the treatment of several diseases. But, HSCs in cord blood are few and their overall function is delayed as compared with the normal bone marrow HSCs. I am interested in making the cord blood derived HSCs better suited for clinical transplantations. So, that's the target, and we are trying to achieve that by studying the factors that help in the development of blood system during fetal life, using small animal models.

Another important alternative source of HSCs could be the use of embryonic stem cells (ESCs), the cells, which can make any type of cell that you find in a human body. But, the HSCs derived from ESCs are not fully functional. For the derivation of HSCs from ESCs, we need to follow the pathways taken during fetal development. Therefore, the studies on fetal development can give important insights to this process as well.

4. What experiences have shaped the choice and nature of your current work?

I did my Masters from the Department of Botany in Delhi University. I enjoyed the old-style science taught there. And I have to say that it is an inspiring place because of the great science done by several generations of scientists in the past. I chose plant tissue culture as my special paper and working in that field made me curious about the potential of animal cells to repair tissue damage. You know that animal organs have limited potential to regenerate unlike plants. I started my PhD in 2003 and the stem cells field moved so fast that in 2006 Shinya Yamanaka and colleagues published ground-breaking research showing that all cells in our body could be made pluripotent and can generate any kind of cell type. For instance, you cannot make a liver cell from a skin cell. But, if you take the skin cell and induce it to become an ESC like cell (called as induced pluripotent cell or "iPSC") by forcing it to revert to an earlier stage in its development, you can generate any kind of cell. So, theoretically and for most practical purposes, you can take any cell from the body and generate any other cell type. If you have a disease related to liver cells, theoretically, you could take any other normal cell of the body and generate normal liver cells.

5. What is a typical day at work for you like?

For a researcher a typical day depends upon what stage of career you are at. For almost a decade of your initial research life, you are mostly in lab doing experiments. For me, life is changing now and I believe that I am going through a transition phase where I want to design new experiments and scientific projects rather than spending all my

time in performing experiments that answer one question. In our field you need to perform so many experiments to prove a point. So, basically even if you know where your experiments are taking you, you will have to spend a lot of time in finishing the project. And I am at a stage where I have more questions that I can answer on my own so I look to make my own team and have a lab that can work on those questions. I am trying to spend less time on the bench and more time in learning how to write projects, arrange for funding, publishing my research to share with my peers. But, this is not always possible as I am still not a fully independent scientist. My work load on many days becomes very heavy with all the different things I would like to accomplish. So I would just say that balancing experiments with strategizing your future scientific life needs a lot of focus and many hours of work.

6. What are the positives of being a research scientist in biology?

I have no idea about that. The most important thing is that I should be satisfied by my work. It is extremely hard for me to think of any other field of work that can satisfy me other than what I am doing right now. There cannot be any bigger positive than this.

7. Are there some character traits that are a natural fit for scientific research? What would these be?

I believe that observation, curiosity and a quest for knowledge are required. And then, you need perseverance in this field. Scientists, as you know them today, were not like this always. Many of them were ordinary people who were just curious, liked to observe, and wanted to know. My favorite scientist - Gregor Mendel, the father of genetics, was a monk and what he could do with simple observations and meticulous recording was incredible. Similarly, Antonie van Leeuwenhoek was a draper, and today, we know him as the father of microbiology. He used hand-made microscopes to observe and know what we couldn't even see at that time with naked eyes. Therefore, there has to be something in you that makes you choose to be a scientist.

8. What are the most frustrating aspects of being a research scientist?

Scientific work needs a lot of experimentation on your working hypothesis on the problem that you work with. Biological systems are very smart and not easy to decode. Therefore, work hypotheses fail more ofte than you would imagine. This is the most frustrating part of the work. About the life of a research scientist, the most common answer is that it takes a lot of time and you get very little financially. If you are very lucky and perform really well starting from your school, you get a job when you are around 35. And as compared with high performing individuals in other professions you get very little money so it can be discouraging for many. Both these factors are understandable but many will not have much of a problem with this.

There is one thing that is very frustrating for me, and that is, how you judge a scientist. What I mean by this is: how do you determine that your science is better than mine. The criteria of judging science can be very subjective, and objective criteria are very tricky. This can make your life, as a scientist, difficult.

9. Has your choice of profession shaped the person you are? If yes, in what way?

Research is one of those professions that in most cases, will bring changes to one at a personal level. You have to learn how to focus, how to let go of certain things at a certain time. Resources available for research are limited, especially in developing countries, so you tend to learn how to manage things well.

You get to train young researchers, who are not really very young. This can bring a lot of contradictions at the work place as it is very difficult for people to change after a certain age. And, in most places, researchers at different levels

are colleagues and sense of seniority is lesser, so you may need to mend your ways in order to keep any personal feelings that contradict this in check.

10. For someone finishing higher secondary school, what is the typical course of higher education to be pursued to become a researcher in biology?

Becoming a researcher in Biology is a long process. After a higher secondary school education, you enrol in a bachelors' programme, followed by Masters, and then look for PhD positions in various research institutions or Universities. Getting a position or a fellowship can be difficult. Also, your specific interests can limit the choice of laboratories where you can go. With a PhD position, doors open for full time research. Industrial research can be taken up after Masters but for academic research you need a PhD, which certifies that you are an expert in the field. A PhD might make things easier in some ways, but even this does not ensure a smooth path. There are limited positions in most academic institutions, and you have to constantly prove your credentials as an independent researcher.

11. Can someone WITHOUT an undergraduate background in biology pursue higher studies in embryology or stem cell research?

It can be done, provided you spend some time in understanding the basics of this science. Without a background in biology, most research institutions may not be open to giving you a research position. Some places have biology-based entrance tests, which can be tricky for someone with no background in the subject. But it's not the same with all of them. To me, the most important thing would be that the candidate should know why he/she is taking up that course.

Biological systems also work on the principles of physics and chemistry so there is scope to understand embryonic stem cells, for example, in a different light. For instance, in a recent project, we are trying to understand how the mechanical properties of the local microenvironment could change the functions of stem cells. In this project, we are collaboratng with other laboratories and trying to learn from each other. Similarly, research groups in biology can consist largely of biologists or bio-engineers, but also need experts in mathematical and computational modeling.

12. Can you recommend a few books written at the popular level, which explain the basics of (a) stem cell research and (b) embryology, and are accessible to school/ college students?

There are several good books on both these topics. For stem cells, Harvard Stem Cell Institute launched an online stem book (http://www.stembook.org). This is a nice resource. Langman's embryology is a good book for basic developmental biology. Unfortunately, most of the books on stem cells and developmental biology are pitched at a level, where readers will need some basic biology background.

13. What are some of the research institutes in biology, in India, that schools can visit? (that welcome visits from school children).

I am sure most of research institutes will be happy to host school children. It is certainly a good idea as children will get first-hand experience in how research labs work. Among some of these places, my alma mater, the National Institute of Immunology in New Delhi will definitely be one. The IITs and the new IISERs will be great too.

I think scientists have to visit schools too, in addition to schools visiting laboratories. This will be more economical. Not very many schools can afford to take their students to research institutes, which are mostly in big cities. If every scientist in India starts giving one day per year to schools, I think it would be a good start.

14. What is embryonic stem cell research and why is the ethics of this research often a topic of debate?

Belief and reasoning can clash at times. To derive embryonic stem cells (ESCs), an early stage embryo, which is a potential life form, has to be destroyed. Scientists believe that research on ESCs can lead to strategies that could lead to alleviation of several life-threatening diseases, but the dilemma is that you have to destroy a potential life form. The question that is often debated is whether an embryo really is a human life and at what stage of development can you really call an embryo a human. This is the crux of the matter, but this central argument can be extended to hours of discussion without actually reaching any conclusion. Therefore, different countries have different laws on ESC based research. The good thing is that we have an alternate in induced pluripotent stem cells (iPSCs), which behave like ESCs, but can be derived from cells of the adult human body through a combination of genetic manipulations that change their fate.

15. What are some of the direct benefits (to society) of stem cell research from the last 10 years?

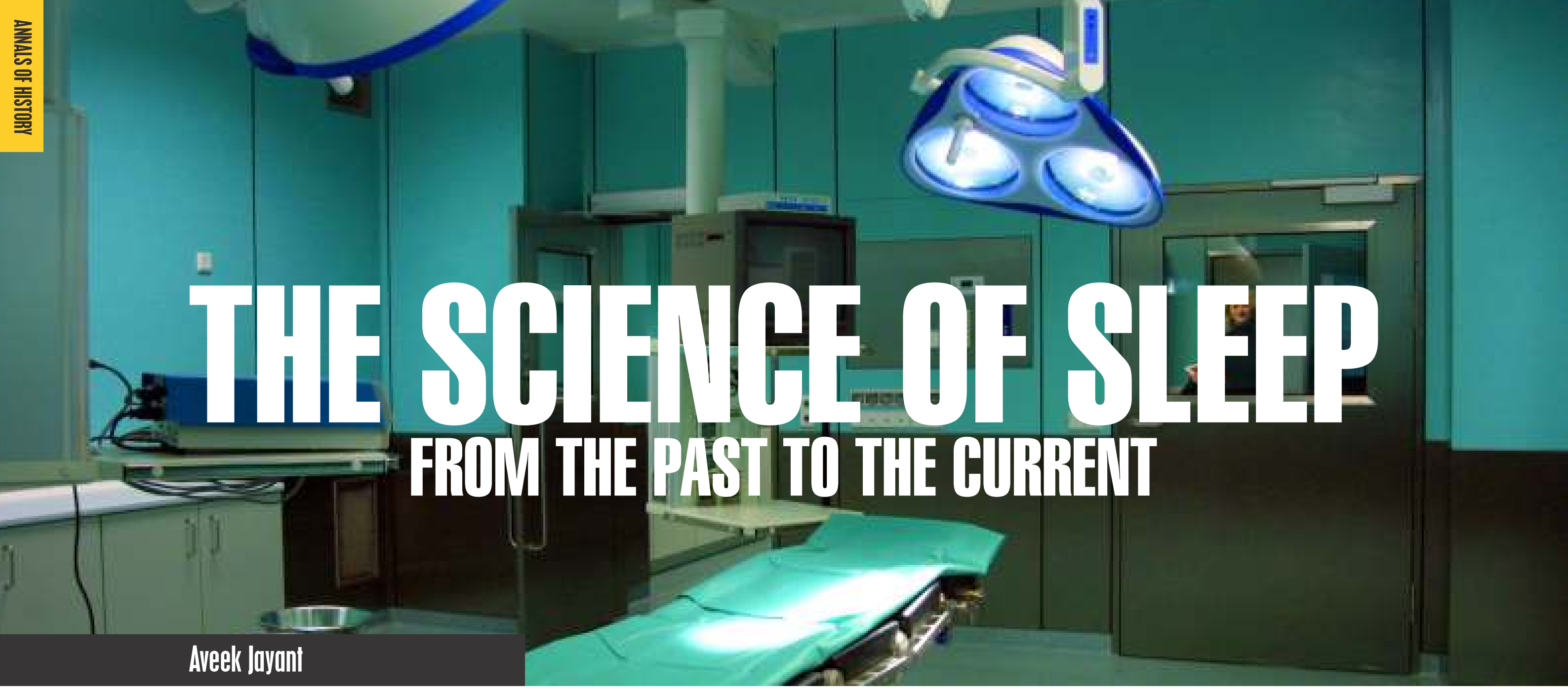
There are three major benefits in studying stem cells. First, you know more about the basic functioning of organisms; second, stem cells have immense potential clinically, and lastly, they are used for drug development. All three are important but we are really looking forward to the development of stem cells as an alternative strategy to curing diseases and other debilitating medical conditions. HSCs have been frequently used in clinical practice since the late 1950s, but other kinds of stem cells are still in limited use. Recent advances have made stem cells more relevant in bone and skin related conditions. Results from tooth and eye related trials have been quite promising. Cord blood derived stem cells are getting more recognition these days, although currently, they are used mostly in blood related diseases. I think there is a lot of promise in this field but, it is going to take some time for this promise to take shape. A very nice resource available at www.clinicaltrials.org provides information about clinical trials undertaken in various fields of biomedicine, including stem cell research.

16. Are there still outstanding questions in our understanding of the development of human embryos?

Oh yes, there are, and I don't think that they will cease to exist anytime soon. Human development is obviously difficult to study but, even if we talk about small laboratory animals, there are many unanswered questions. Obviously the questions that we have today are very different from many of the questions we have been asking in the past, and are aimed at understanding the functioning of stem cells at the cellular, molecular and chemical levels in greater detail.

17. Do you have any suggestions on how science can be taught in schools to encourage more students to pursue a career in biological research?

I do not know much about how school textbooks and teaching strategies look today but, I know it has not been very good in the recent past. There has not been much scope for creativity in classrooms. Not only science, school education, overall, needs to encourage curiosity, innovation, out-of-the-box thinking and critical questioning. Education needs to be more practical, interactive and communicative. Learning is only a part of education. Creativity has to be encouraged and rewarded. Science is all about observing phenomenon happening in nature and trying to understand it; technology makes this knowledge available for use by the larger society. School children hardly know any Indian scientists, which could be an important aspect to remedy. Local inspirational stories are missing. More frequent conversations with the Indian scientific community can really help students in schools. Scientists could visit schools, tell children their stories, help students identify their interests and inspire them to follow their dreams.



THE SCIENCE OF SLEEP

FROM THE PAST TO THE CURRENT

Aveek Jayant

How long has the use of anaesthetics during surgical procedures been in existence? What were the pitfalls encountered in finding an ideal anaesthetic? How is an ideal anaesthetic defined? Who were the main scientists and doctors involved in getting anaesthesia to the present level of sophistication? This article throws light on the history of this important medical aid.

Introduction

"To trace successfully the evolution of any one of the learned professions would require the hand of a master- of one, who like Darwin, combined a capacity for patient observation with philosophic vision. In the case of medicine, the difficulties are enormously increased by the extraordinary development…. the rate of progress has been too rapid for us to appreciate, and we stand bewildered…" (Sir William Osler, 1849-1919, address to the British Medical Association 1897)

On terra firma- what I do and what I am about to do!

All of us have, at one time or the other, been either moved to tears or made to laugh out loud by the actors in a play or a film. When the play is in motion or the film reel rolls, it seems as if only the main characters on stage are there for the performance. Yet each of these performances is actually made real by the tremendous efforts of those who are behind the scene-those who handle the lights or costume, or prompt an actor when he or she forgets, even those who make sure the curtains come off and go on at the right times. The discipline of anaesthesia is akin to these backstage players. While removal of teeth or nails appears simple, surgery can be complicated - such as mending a broken heart.

I currently spend the greater part of my working life putting people to a state of painless sleep, particularly when their hearts are repaired. This is in addition to monitoring and maintaining, as close to health as possible, their other organs. I also assist in imaging the heart during the procedure, and finally, have a key role in ending the operation in delinking life support and getting a patient back to his feet in the intensive care unit. In this article, I propose to take you on a journey through modern anaesthetics, a snapshot of its evolution, and through it all, convince you of how interconnected the world of knowledge actually is!

From ancient times

The concept of enabling sleep as one went about refashioning an organ is actually ancient. The Bible refers to how the Creator induced a temporary sleep to remove a rib from Adam[1]. Sumerian artefacts depict the use of opium poppy in 4000 BC (the use of opioids as analgesics continue to be the mainstay of anaesthesia even

to this day) [2]. Susruta, the pioneer Indian surgeon, refers to the use of wine as a soporific# to induce temporary sleep[3]. He is also believed to have initiated the use of cannabis[2] in 600 BC; probably extrapolated from the sleep inducing effects of bhang, consumed on festivals like Holi! The Latin Americans used home grown coca, which is refined to produce modern day cocaine[2], also one of the first local anaesthetics. Yet others, not as observant, would advise people to chew on lettuce or bite on a stick or used a blow to the head to dull the pain that any surgery would bring forth[4]!

A statue dedicated to Sushruta at the Patanjali Yogpeeth institute in Haridwar.

Source: https://en.wikipedia.org/wiki/Sushruta_Samhita CC BY-SA 3.0.

#= drug that causes sleep.

Over time, alcohol and opium became the predominant drugs to be used, but had many problems, among which were the possibility of both inadequate and over dosing (the latter, deadly). Neither was enough to completely ablate the pain of surgery[5]. All in all, the eminent anatomist and surgeon, John Hunter described surgery as a *"humiliating spectacle of the futility of science"* and that of the practitioner as a *"savage with a knife"*[6].

The birth of inhalational anaesthesia

Modern day anaesthetic practice seems largely focused on the administration of medicinal gases via a device into the trachea and from there on the lungs. This began in the mid-18th century when William Morton demonstrated the use of ether at the Massachusetts General Hospital (MGH) in Boston.

The first use of ether as an anaesthetic in 1846 by Morton.

Source: Ernest Board - http://catalogue.wellcome.ac.uk/record=b1203716. Public domain.

However, halogenated alkanes, and not ether, are the main anaesthetic gases in use today. Components of the admixture that have not changed are oxygen and carbon dioxide. Anaesthesiologists have always been preoccupied with the administration, control and composition of these two gases in the breathing mixture since they would inevitably be present at all times.

Joseph Priestley[7] (1742-1786) showed that heating mercuric oxide could keep mice alive longer in a closed space while Robert Hooke managed to keep animals alive by blowing into their lungs[8]. Priestley's communication across the English Channel to the French chemist Antoine Lavoisier (1743-94) led the latter to suggest that the heating of mercuric oxide released an enigmatic new element which he called 'oxygen'. It was left to Humphry Davy (1778-1829), a school dropout, to show that the currency of metabolism was the uptake of oxygen and the production of carbon dioxide. John Haldane provided the logical experimental evidence to this theory by designing apparatus that could accurately measure these gases as they made their way in and out of living things; he coined a

phrase that an editorialist in the anaesthesia textbook, 'Miller's Anaesthesia', stresses is the primary training of every modern day anaesthesiologist: "*anoxemia* (an abnormal reduction in the oxygen content in the blood) *not only stops the machine but wrecks the machinery*". As the first year doctoral student enters our portals, we teach her that the primary religious duty of anaesthesia is to monitor, correct and maintain adequate supply of oxygen to tissues as our surgical colleagues play challenge to the processes of nature. Failure means cardiac compromise and ominous hypoxic (caused by lack of oxygen) damage to the brain as cells die from failure of cellular respiration. So, even as anaesthesiologists focus on putting people to sleep, they have the important function of maintaining the stability of the cardiovascular and respiratory systems, a theme that we will deal with in some depth later.

The actual birth of modern day anaesthesia has a longer history than in the public imagination, and like other momentous events in general history, not free of controversy. If one were to cite a figure who was the most apt to be the father of anaesthetics, it would probably be Humphry Davy[9] (1778-1829), and not Horace Wells (1815-48) or William Thomas Green Morton (1819-68). It is however, Morton's demonstration at the MGH on October 16, 1846 that is celebrated all over the globe as World Anaesthesia Day. Davy was not an ordinary person - at 15 years when the death of his father had left him and his family in extreme poverty, he decided to commence a life of self-learning. His study plans at that time detail that he wanted to be a chemist, physician, geographer, mathematician, astronomer and logician - all at the same time! Davy did contribute to each of these fields through the discovery of six elements in the periodic table; or through inventions to facilitate mining, improve agriculture, and art conservation[9]. It is his study of biologic gases as a physician at the Bristol Pneumatic Institute that set the ball rolling for anaesthesia. As a preliminary step, Davy set out to study on himself which gases were safe to inhale without causing serious injury - some were truly risky, such as, his experiments to inhale carbon monoxide, which he described as an agent that would cause his pulse to become 'rapid and thread like', nearly killing him. We all know that this gas is deadly[10], as it is colourless and odourless and inhibits the oxygen transport function of haemoglobin (Hb) (its affinity for Hb is 200 times greater than that of oxygen), besides inhibiting cellular respiration[11]. His efforts to use carbon dioxide to dull the senses were funnier - it does (and his was one of the first descriptions of this effect)[12] in patients with chronic lung disease causing them to lose full consciousness. It is his adventures with nitrous oxide, however, that are of direct consequence for anaesthesia. Breathing pure nitrous oxide, as he demonstrated to himself, completely abolished his toothache. It was incremental to suggest its potential use in surgery[13]. He was all of 21 years old, and the psychotropic[#] effects of that gas were demonstrated by his writing poetry under the influence of nitrous oxide.

Psychotropic = drugs that affect behaviour/mood/activity.

"Gentlemen, this is no humbug"

Across the Atlantic, another entirely different agent was being used in country fairs to produce a similar transformed state, which was entirely reversed when one stopped breathing the vapour that caused this. These were in the form of 'ether frolics', and the agent was diethyl ether. At the forefront of these endeavours were a motley crowd of physicians, chemists and dentists - Gardner Quincy Colton, Horace Wells, Crawford Long, Charles Jackson and William Thomas Green Morton. In as much as their efforts, singly and together, laid the foundations of the whole science of inhalational anaesthesia, they undid much of their effort in attempting to gain individual fame and money over any sense of collective scientific achievement. If there was going to be a 'first' person to have used a true anaesthetic (which nitrous oxide was not) in the form of 'etherisation', it is near certain that it was Crawford Long (1815-78)[14]. Long, a physician, noted that injuries sustained during the ether frolics were often associated with painlessness. In 1842, he successfully used diethyl ether as an anaesthetic to remove a cyst from the neck; his second attempt was only part successful. Unsure of reproducibility, he put off any publicity till he himself was sure that anaesthesia was produced by the ether and "not the effect of the imagination".

Horace Wells, a dentist, was the next in this line of daring men. He successfully used nitrous oxide in dental extraction, but his attempts to seek public recognition at a demonstration at Massachusetts General Hospital (MGH) in early 1845 was met

with some moans and groans from the patient (a feature of this anaesthetic though not proof of its total lack of efficacy) and scepticism from the audience. A pupil, Morton, in the audience now jumped into the fray and set out to better his teacher's effort. Morton was sure it would work, but wished to be the high priest at a new ritual - he would refuse to share the composition of his "Letheon" (it was diethyl ether mixed with a dye and some additional scents to make it feel and seem an invention that he alone owned) but successfully used it at the MGH on October 16, 1846. In hindsight he was very lucky - he used a contraption that would resemble a modern day teapot (the nature of the exact device used is mired in controversy) to anaesthetise a young male with a large, vascular tumour of the neck, to be excised by John Warren, the chief surgeon at MGH. A modern day anaesthesiologist would be cautious - blood loss, loss of airway control, air embolism… but for Morton, fortune favoured the brave. At the heart of his success were the very different physical-chemical properties of ether as compared to nitrous oxide. The offset of actions of ether would be much more gradual than nitrous oxide. Thus, in the days of approximate action, when small errors such as disconnection, dosing, and premature cessation could mean that the patient suddenly woke up in the middle of surgery, to his horror and that of his treating physicians, these errors were more likely of this dramatic kind, when the agent was nitrous oxide than ether. Morton, however, never really lived to enjoy his success: the mad fallout of who should get credit for this success (his as against the claims of Wells, Long and the others) coupled with his passionate desire to promote himself, ensured that he died very young, at 49 years of age, unhappy and insolvent!

Recollections from a long while ago

What determines how gas delivered into a patient's lung will cross the alveolar membrane into the bloodstream and then be carried by the cardiovascular system via the left heart to the brain and spinal cord to exert its actions in anaesthesia? In mixtures of gases, the relative contribution of each gas to the whole pressure exerted by the gaseous mix is in proportion to their presence in the gas (Dalton's law of partial pressures). Thus, if the atmospheric pressure at sea level is 760 mm Hg, nitrogen (which makes up about 78% of this mix we call "air") contributes 78/100 X (760), i.e. 592.8 mm Hg of the total pressure of 760 mm Hg exerted by this mixture.

The total pressure in a gas mixture is the sum of the partial pressures of each individual gas

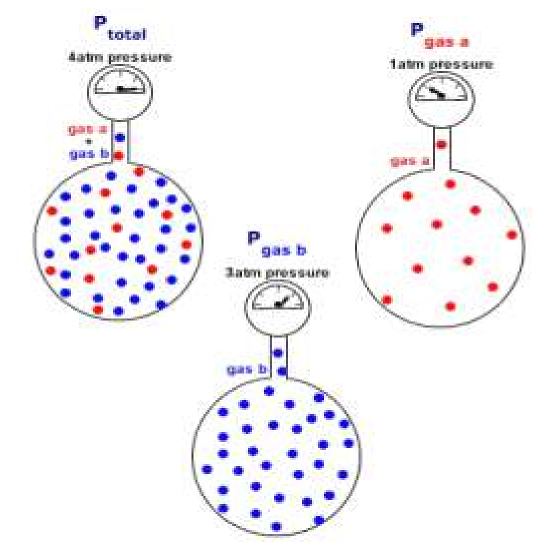


Illustration of Dalton's Law of Partial Pressures

Just as we think of the diffusion of water into the root of a plant from the soil as a result of the higher concentration of water (when we pour it into a flower pot) in the soil relative to the root, we can think of gaseous exchange being determined by the relative **partial pressures** of a gas. These diffusion processes govern the transfer of oxygen across the alveolar membrane from atmospheric air to the haemoglobin in our blood: the venous blood has low oxygen tensions relative to the air in the breathing mixture and passive transfer occurs across the alveolar capillaries which are designed to be thin and ready to allow this. What complicates the picture, somewhat, is the presence of two different states of matter:

> Solubility is the volume of gas that dissolves in unit volume of liquid at a given temperature; it is usually measured as the Ostwald coefficient or a partition coefficient - δ. Imagine a gas in a closed chamber in contact with a liquid; the ratio of the concentrations of the gas in the liquid phase to that in the gas at equilibrium (i.e. when the partial pressures equalise and bring the transfer to a stop obeying the more general laws of all diffusive transfers across a concentration gradient) is the partition coefficient δ.

liquid and gas - blood as liquid and atmospheric air as gas. Apart from partial pressure, the transfer of gas from a gaseous phase across a membrane into a liquid is also influenced by its *solubility* in that liquid.

Now the δ value of diethyl ether which Morgan used is 12 whereas that of poor Wells' nitrous oxide is only 0.47; at any given time there is about 12/0.47 = 25 X as much ether dissolved in blood as nitrous oxide at the same partial pressure. Suppose Mr Wells were to suddenly stop or run out of nitrous oxide, there is very little nitrous oxide to well out of the blood to sustain the partial pressure of nitrous oxide needed to maintain anaesthesia; Mr Morgan however, even if he were to fall asleep, has a huge volume of diethyl ether within the patient's bloodstream. This can diffuse out as gas even if her physician were to stop administration and this diffused gas would continue to keep the patient asleep for a while, explaining the two different courses of those historical anaesthetics.

However, there is a flip side to the diethyl ether (it has virtually no place in modern anaesthesia). Imagine attempting to put a hypothetical patient to sleep using the ether - now what acts on the brain to cause anaesthesia is the undissolved 'free' gas in blood that crosses the blood brain barrier. When a very soluble gas like ether is used, a whole lot of it is just guzzled by the large blood volume in the patients as dissolved (and hence of no utility) ether, before any significant undissolved concentration is achieved for reaching and dulling the patient. Etherisation, therefore, while offering a large safety margin in keeping patients asleep once they are anaesthetised, takes a long while to achieve - enough to give hospitals, anaesthesiologists and surgeons the funny smell that many of us associate with hospitals (this is historical, since the era of etherisation is virtually over). Further, in a busy world like today, where hospital facilities are vastly outpaced by patients needing to use them, it would be a big waste of time waiting for them to wake up from the dissolved ether in their body.

"In sorrow thou shalt bring forth children"

A parallel drama was being enacted in Britain just about the same time that Morgan et al. were playing it out in the United States. At the heart of this enactment was James Young Simpson; primarily an obstetrician, but a very clever and versatile one. Simpson (1811-90) was also acutely interested in drugs that would abolish pain. When etherisation was described in the US, he was quick to obtain a sample, and use it in a complicated childbirth in preference to mesmerism. A witness was to remark *"this Yankee dodge beats mesmerism hollow".* Meanwhile, organic chemists had started to synthesise many more compounds, and chloroform arrived in the 1830s. It had a slightly lower blood gas partition coefficient than ether (which was already getting on everyone's nerves given its 'volatility') and was also not as inflammable. Simpson used it first on himself, then on his niece, and gradually on women to abolish the pain of childbirth[14]. Simpson apparently encountered opposition to its use as theologians suggested that child birth was meant to be painful as punishment for the original sin (as stated in the Bible); it is currently believed that this theologic opposition was mild[14]. Another key figure in Britain was the legendary John Snow - the father of modern epidemiology (the statistics of modern medicine, and its foundation of using experiments to decide what is right instead of the whim of a caregiver) who would define the stages of a typical anaesthetic and warn of the hazards of excess. However, chloroform and ether, their historical importance notwithstanding, would probably never have stood the test of time: low potency, long times to effect and wearing off, inflammability (since the use of oxygen as also the cauterisation of surgical wounds using electrical energy can make a dangerous mix to set off fires in operating rooms) would be their disadvantages. The demand for pure agents, and the neighbouring revolution in chemical synthesis in the early 20th century would mean their replacement by potent, relatively non-toxic agents such as the fluorinated hydrocarbons in use today. The latter have much better blood gas partition coefficients (with 0.42 being that of desflurane, the newest, which is the fastest to act and disappear and 1.15 that of isoflurane which is among the most commonly used today), do not support combustion, are quick to act, and also fast in wearing off, such that most people could have an operation in the morning in hospital, and help make dinner at home in the evening[15]!

The Hindi film discourse and real being different from reel

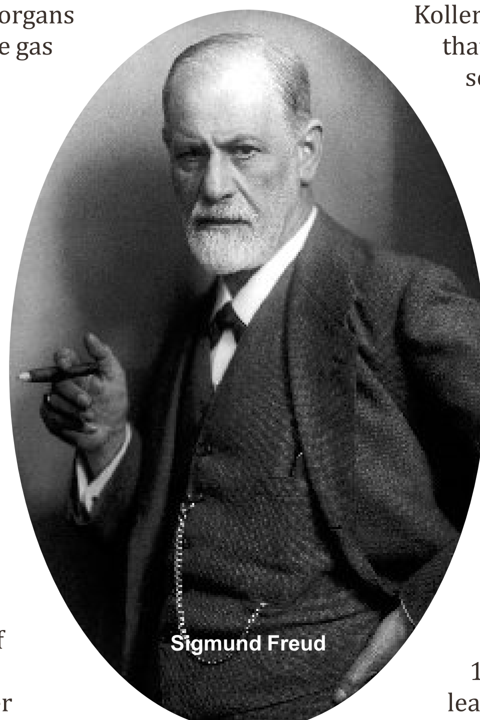
Most depictions of anaesthesia on television and in the theatrics surrounding accident or childbirth in our films are far from real. They

usually begin with a masked man or woman stuffing the victim's nose and mouth with a gas and as she thrashes about in pain from the original trauma or from being so restrained, she dulls to sleep. Whether or not she will wake up is usually decided by the plot - there is either dramatic recovery as we approach the end or an agonising wait for the missing hero who would then wave his magic wand. In contrast, most anaesthesia commencements today are made using intravenous drugs, in the quiet of hundreds of operating rooms all over the world.

Unlike gas, there were several impediments to the development of *intravenous* anaesthesia - some of which were the disastrous effects of inadvertent microbial contamination (leading to sepsis), the complicated apparatus required, in the form of needles and syringes, and the dependence on metabolism by organs for termination of action (unlike gas which could just be breathed out). The first recorded intravenous anaesthetic was the injection of alcohol using a contraption of dog bladder and goose quill into a dog who went to sleep and yet managed to awake and survive the onslaught; the hero in question was Christopher Wren, founder of the Royal Society in Britain in 1656[16]. The development of injectable apparatus in the form of needles (Francis Rynd 19th century) and syringes (Alexander Wood, also the same time) would be of no avail till the synthetic chemistry revolution in the later part of that century. Alexander von Baeyer (1835-1914)[17], chemist and Nobel Laureate (1905) was one such giant who synthesised indigo, fluroscein, and barbituric acid (the parent of modern day barbiturates used to anaesthetise and stop seizures). The industry - science complex in the first part of the 20th century then took over in the synthesis of a variety of agents with diverse structures - propofol, etomidate and the benzodiazepines. Today, these agents are either used to make the induction of the anaesthetic state pleasant, transiting to gas anaesthesia thereafter, or used as the sole anaesthetic. Gaseous anaesthesia appears to still be the most commonly used - easy administration, non-dependence on metabolism, elimination in those who have diseased livers or kidneys (the main sites for all drug metabolism), faster offset because of these properties - all these gives it an edge. Since like all diffusion, this ends with a state of equilibrium, measuring the concentration of these gases in the breathing mixture is an estimate of their concentration in the brain where they act. This measurement can aid in correcting both over and under-dosing.

New arms in the inventory: local anaesthesia

It was known in the mid18th century that cocaine applied to the tongue would numb it. However it was the psychedelic experimentation of Sigmund Freud and his colleague, Carl Koller at the Vienna General Hospital that would bring anaesthesia a new set of arms. Koller's colleague, who accidentally licked cocaine off a pen knife, found his tongue numbed. His account to Koller, immediately prompted instillation of cocaine into the eyes of a frog and a guinea pig (Koller was an aspirational ophthalmologist), which made the conjunctiva and cornea insensate. A presentation to the Heidelberg Ophthalmological Society in 1884 started a new train - injection into nerves (Halsted, the great surgeon) or into the spinal canal (Bier 1897). The latter approach would lead to numbing of a whole set of nerves at one go. Local anaesthesia was once believed to be safer and superior to general anaesthesia. Whilst there are many limitations on the complexity and anatomic extent of surgical work that can be accomplished with local or regional anaesthesia, this tool has come to stay - from offering superior pain relief than achieved with intravenous drugs[18], to enabling faster surgical recovery[19], preventing persistent pain after surgery[20], or preventing lung complications from breathing and coughing better when the lung or regions nearby are operated upon[21].


Sigmund Freud

Trail blazing science in the middle of war

The 20th century was a violent epoch, with two world wars scarring its first half. With these events in the background, the demand for complicated surgery surged more than ever before. In addition to attending to casualties of war, surgeons were now attempting to remove complicated organs such as the lungs during peacetime or performing palliative surgery for life threatening heart conditions[22]. Precise control over the cardiac and respiratory systems in the interim period of surgery meant demand for sophisticated machines that could deliver exact concentrations of gas, accurate volumes of air at just the right composition, instruments akin to weather gauges predicting an impending crisis and so on. The immediate periods of the Wars often meant a standstill for peace - time science (economic squeeze and conscription in the War for scientists and physicians alike), but the birth of quantum mechanics during this period, describing the behaviour of subatomic particles would spurn a revolution in the development of devices and technologies that lie at the heart of our modern lives: transistors, computers, the electron microscope and magnetic resonance imaging. Anaesthesia is among those disciplines in medicine that are most heavily reliant on these technological revolutions.

Modern ventilators use microprocessors to time the onset of a ventilator cycle or end a mechanical breath. The science of spectrophotometry lies at the heart of the continuous measurement of blood oxygen (thus warning anaesthesiologists of low levels well before their ominous effects on the central nervous system can occur), sophisticated monitors mean providers can focus on other tasks, such as detecting cyanosis (appearance of blue colour on the skin due to lack of oxygen) with the naked eye, or provide minute to minute data on the prevailing blood pressure or filling and emptying of the human heart.

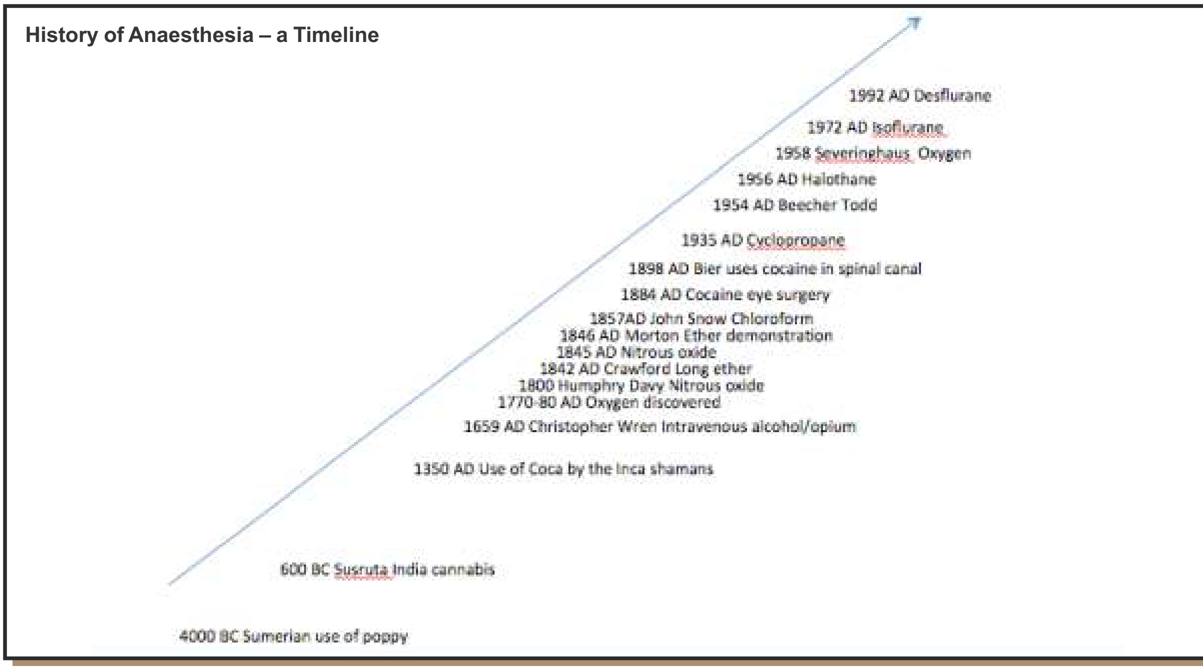
Anaesthesia and technology: the harmony is proven by our report card

Anaesthesiologists would first recognise low oxygen levels from the colour of the tongue or mucous membranes, or the blue colour of deoxygenated blood. During surgery, this could, often, be a little late in the day for meaningful action. Today a pulse oximeter analyses the relative concentrations of oxygenated and deoxygenated blood non-invasively from the finger tip on a beat- to- beat basis; the instrument uses spectrophotometric principles to deduce this value and alert the physician to quick action. Infrared spectrophotometry identifies whether or not a tube is placed correctly in the trachea instead of the oesophagus (anaesthesia trainees and experts can accidentally intubate the food pipe instead of the trachea - thus the stomach gets ventilated, instead of the lungs).

Electrocardiograms are generated from surface electrodes on the chest; blood pressure measurements are automatic using the principles of oscillometry; and the anaesthesia provider can also use a number to quantify consciousness (allowing him to titrate the quantity of anaesthetic to be delivered). There are various indices used today to quantify conciousness[23]. These indices are developed using the raw electroencephalogram data (EEG, akin to the ECG these are surface waves reflecting electrical activity within the human cortical cells of the brain). They are a measure of the order in the brain[24], which increases with deepening anaesthesia. A research group I have worked with has developed a computer based system that automatically increases or reduces the amount of anaesthesia, without requiring the anaesthesiologist to do this manually[25].

However, if one were to be driven to think that anaesthesia is inherently safe, the Russian army experience in 2002 would caution us. In 2002, a hostage crisis confronted the army in Moscow in an opera house; it sprayed fentanyl, an analgesic opioid (besides causing analgesia it also causes sleep and potent dose dependent respiratory depression) to end the impasse. A good 129 attendees (15% of the total attendance) – including the innocent as well as terrorists, died[26].

Henry Beecher and Donald Todd were the first to systematically assess the risks of anaesthesia; their study determined that about 1:2000 deaths in the operation theatre were directly related to anaesthesia management. If a particular technique (muscle relaxation to facilitate surgery) was used, the number was 1:370[27]. Neuromuscular blocking drugs (that work at the nerve terminal with muscles, like botulinum toxin or nerve gas) can be deadly, if their residual action is not detected. This study proved that if one was more careful and monitored the effects of these drugs, it could lead to more anaesthesia safety. In



History of Anaesthesia – a Timeline

a large country, such as the United States of America, 2,211 patients died from an anaesthesia related cause in the period 1999-2005; the study estimated that the risk of anaesthesia was of the order of 1.1 per million population per year, probably lower than that of a terrorist strike![28]. Similar impressive numbers are reported from Australia[29]. In our country, roughly 12 people per 100,000 population die of a road accident per year[30]! Thus travelling in a bus or a car may be more unsafe than being put to sleep for surgery. The synthesis of human skill and technology has made anaesthesia a safe specialty, and this success story is evidence of the potential of good science in human life. We might, however, end this section with caution: while anaesthesia related mortality has steeply fallen all over the world, there is a big divergence between countries in the developed world and the underdeveloped or emerging economy status countries like ours[31]. This may be due to a combination of poor technology use, bad science (and by extension inadequate science education by educators) and poor economic spending on healthcare.

Beyond anaesthesia: from an enabling specialty to a therapeutic partner

Anaesthesia is an enabling specialty: it helps perform surgery safely, but the actual therapeutic benefit is that of the surgical procedure itself, not the anaesthetic. It thus behoves us to be as safe as possible. However anaesthesia can also have therapeutic effects. Curare, a dangerous drug has been used to abolish the excruciatingly painful spasms associated with tetanus[32]. Anaesthetics have been shown to prepare the heart for disaster - a term called pre-conditioning, just like how we save money in a bank to prepare for tough times in the future[33]. A polio epidemic in Denmark was the impetus for an anaesthesiologist Bjork Ibsen to keep children with respiratory failure alive (secondary to the paralysis induced by polio virus) by use of positive pressure ventilation[34]. In the spirit of our highest traditions as doctors whose sole aim is to cure and help others in need, this ventilation was provided by hundreds of volunteer anaesthesia trainees, anaesthesiologists and other medical doctors round the clock manually! In Ibsen's action lay the nucleus for founding our modern day intensive care units[34]. Virginia Apgar, an anaesthesiologist formulated the first score[35] to sort newborns into those who would need further attention and those who could manage alone - her score continues to be in use to this day, and is taught to all doctors during their first paediatric rotation. Anaesthesiologists, driven by their own need to accurately measure oxygen tension in blood, have contributed substantially to the development of technologies, such as electrodes for the measurement of arterial oxygen[36]. Anaesthesia management can affect the rates of tumour recurrence after cancer surgery[37], or the rate of heart attacks in patients with cardiac disease after non-heart surgery[38].

Extending the knowledge frontier: can being asleep teach you about what it is to be awake?

The quantum mechanics era, and the giant steps made in medical imaging as a result of these studies, has already been referred to; today, it is possible to use appropriate tools, such as functional Magnetic Resonance Imaging (fMRI) or Positron Emission tomograms (PET), to correlate brain function with anatomic areas - in health or in disease[39], [40]. Imagine an anesthetised patient who is undergoing fMRI – his visual cortex is active during the drug induced hypnotic state. Does it not tell us that the visual cortex activity has no correlation with the awake or asleep state? Likewise, anaesthesia appears to be associated with functional uncoupling of the parietal-frontal cortical loop. What this means literally is that, although, these individual areas may or may not be active, their cross talk is what causes cognition (simplistically the parietal area is the sensor, the frontal the interpreter of sensation). Cognition is broadly the way we see, think, feel or hear the world around us. All of these sensations are abolished with anaesthesia. Anaesthetic drugs do not impact the activity of individual regions but abolish their cross talk. Thus, anaesthesia processes provide an insight into how the brain works when awake.

Ahoy ! Ahead.

Our quest to understand the natural world within and outside ourselves continues in an unbroken tradition from pre-historic times. This quest asks us to forever persevere in furthering the frontiers of knowledge; today anaesthesiologists guide heart repair during surgery, use ultrasound to inject local anaesthetic in the proximity of nerves etc. Anesthesiology is a super-specialised branch with sub- specialties in paediatrics, cardiology, neurology, pain and intensive care. There is only one way forward - to be constantly awake and alive in the primeval spirit that science is all about.

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THE SAGA OF ATOMIC WEIGHTS

Sushil Joshi and Uma Sudhir

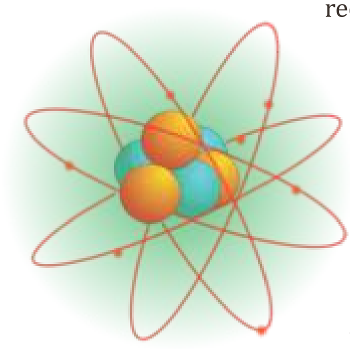
Who were the first people to think of the concept of atomic weights? How were atomic weights of elements first calculated? In this article, the authors explore the long scientific journey from the origins of the widely used conceptual framework of atomic weights to the debates on the topic prevalent even today.

Introduction

The atomic weight of elements is one single idea that distinguishes Dalton's atomic theory from earlier atomistic ideas about the nature of matter. The concept of atomic weight also makes possible all the quantitative predictions about chemical interactions, and their outcomes. We take the idea of atomic weight as given, and almost never think of it as a conceptual framework which is the result of intense debates beginning in the early nineteenth century. The saga of atomic weights is not only extremely interesting, it also gives us an understanding of the way scientists work. This story takes a winding route, and is enriched by the contributions of several leading scientists of the time. Some of the debate around this concept continues even today.

The beginning

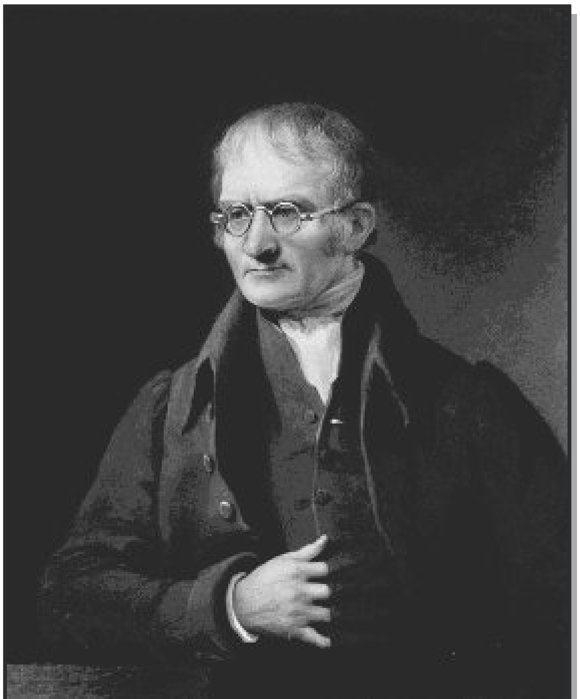
It is well known that ideas of an atom-like particle were present since the ancient times with Kanada in India; and Leucippus and Democritus in Greece, having talked about an ultimate particle. However, the modern atom owes its 'existence' to the efforts of several chemists, culminating in Dalton's atomic theory.



In the eighteenth century, chemists started studying chemical phenomena quantitatively, resulting in the postulation of several laws of chemical combination. These included the law of conservation of mass, law of constant proportions, and the law of reciprocal proportions.

John Dalton, looking at these laws, thought that they could be explained only if we assumed matter to be constituted of some ultimate indivisible particles. If he had stopped with this assertion, the modern atom would not be a tool to understand, explain and predict the course of chemical reactions. Dalton enunciated that:

1. All matter is ultimately composed of atoms, which can neither be subdivided nor changed into one-another.
2. Atoms can neither be created nor destroyed.
3. All atoms of the same element have the same weight, and are similar in size and shape etc.
4. Chemical change is the union or separation of atoms as a whole.



British physicist and chemist John Dalton (1766-1844) by Charles Turner (1773-1857) after James Lonsdale (1777-1839) - Public domain. This image is available from the United States Library of Congress's Prints and Photographs division under the digital ID cph.3b12511

These postulates explained the above mentioned empirical laws of chemical combination. Moreover, the theory was interpreted to predict the law of multiple proportions. When this prediction was found to be true, it added strength to Dalton's theory. The theory had secure foundations. It should be noted that all these laws were quantitative statements about chemical reactions, and led to an explanation, which was also quantitative.

Dalton realized this very well. Writing in his '*A New System of Chemical Philosophy*' in 1808, referring to the observations made and conclusions derived by Robert Boyle a century earlier, the laws of chemical combination, and especially the law of constant proportion, he said:

> *"These observations have tacitly led to the conclusion which seems universally adopted, that all bodies … are constituted of vast numbers of extremely small particles, or atoms of matter, bound together by a force of attraction, which is more or less powerful according to circumstances."*

> *"… This conclusion, which appears completely satisfactory; … we have hitherto made no use of it, and that the consequence of the neglect has been a very obscure view of chemical agency..."*

The 'neglect' which Dalton talked about had to do with postulate 3 of his theory. He had a vast amount of data, and on the basis of that meticulous data, he concluded,

> *"In all chemical investigations, it has justly been considered an important object to ascertain the relative weights of the simples which constitute a compound. But unfortunately the enquiry has terminated here; whereas from the relative weights in the mass, the relative weights of the ultimate particles or atoms of the bodies might have been inferred, from which their number and weight in various other compounds would appear, in order to assist and to guide future investigations, and to correct their results. Now it is one great object of this work, to shew (sic) the importance and advantage of ascertaining the relative weights of the ultimate particles, both of simple and compound bodies, the number of simple elementary particles which constitute one compound particle, and the number of less compound particles which enter into the formation of one more compound particle."*

Having said this, Dalton proceeded to calculate the weights of different ultimate particles, i.e., atoms.

Dalton calculates atomic weight

It was amply clear to Dalton that atoms were so tiny that it was futile to attempt to weigh them singly. But, one may surmise that he could have calculated average weights. However, remember that in the beginning of the nineteenth century, all that was known was combining weights of various elements when they reacted with other elements. For example, when hydrogen reacted with oxygen, it was always in the proportion of 1g of hydrogen and 8g of oxygen. But how can you calculate atomic weights of these two elements from this knowledge?

Weights of the two elements involved in the reaction do not tell you anything about the number of atoms of each element participating in the reaction. And there was no way Dalton could

1 Dalton called smallest particle atom, whether of elements or compounds.

determine the number of atoms in, say, 1g of hydrogen or 8g of oxygen.

In other words, you either had to know the formula of water *a priori* or you had to know the number of atoms contained in a specific weight of each element. As one can now appreciate, Dalton had no way of knowing either of the two. But that did not deter him.

Instead, he made certain assumptions to complete the task. The assumptions turned out to be wrong, but his Ingenious logic and improvisation had important consequences.

Let us look at the problem in a more systematic manner. From Dalton's theory, firmly established on a solid ground of chemical arithmatic, the obvious conclusion is that elements enter into chemical reactions as whole atoms. So we can write several formulae for water.

Dalton said

> *"If there are two bodies, A and B, which are disposed to combine, the following is the order in which the combinations may take place, beginning with the most simple: namely,*
>
> - *1 atom of A + 1 atom of B = 1 atom of C, binary.*
> - *1 atom of A + 2 atoms of B = 1 atom of D, ternary.*
> - *2 atoms of A + 1 atom of B = 1 atom of E, ternary.*
> - *1 atom of A + 3 atoms of B = 1 atom of F, quarternary.*
> - *3 atoms of A + 1 atom of B, quarternary.*
> - *And so on*
>
> *The following general rules may be adopted as guides in all our investigations regarding chemical synthesis.*
>
> 1. *When only one combination of two bodies can be obtained, it must be presumed to be a binary one, unless some other cause appears to the contrary.*
> 2. *When two combinations are observed, they must be presumed to be a binary and a ternary.*
> 3. *When three combinations are observed, they must be presumed to be one binary, and the other two ternary.*
> 4. *When four combinations are observed, we should expect one binary, two ternary, and one quaternary, etc."*

From the application of these rules, to the chemical facts already well ascertained, he proceeded in the following manner. According to Dalton, nature was simple. If two elements combine to form a compound, they shall do so in the simple ratio of one atom each. If more than one compound is formed by the combination of the same elements, other ratios may be considered, as given above.

Let's take the example of water.

In the early nineteenth century, only one compound of hydrogen and oxygen was known, viz., water. Thus, using Dalton's method, one atom of hydrogen would combine with one atom of oxygen to give one 'atom' of water. In actual weights, 1g of hydrogen combines with 8g of oxygen to produce 9g of water. So, one can conclude that 8g of oxygen would contain as many atoms of oxygen as there are hydrogen atoms in 1g of hydrogen. Therefore, every atom of oxygen would be 8 times heavier than an atom of hydrogen.

As hydrogen was (and is) the lightest element known, Dalton assumed the weight of a hydrogen atom to be 1 and using this as the unit of atomic weight, he calculated atomic weights of several elements and compound bodies.

1. **Hydrogen, its relative weight 1**
2. **Azote (nitrogen) 5**
3. **Carbone or charcoal 5**
4. **Oxygen 7**
5. **Phosphorous 9**
6. **Sulphur 13**
7. **Magnesia 20**
8. **Lime 23**
9. **Soda 28**
10. **Potash 42**
11. **Strontites 46**
12. **Barytes 68**
13. **Iron 38**
14. **Zinc 56**
15. **Copper 56**
16. **Lead 95**
17. **Silver 100**
18. **Platina 100**
19. **Gold 140**
20. **Mercury 167**

The voluminous challenge

This was a time of great activity in chemistry, with many chemists trying to lay the foundations of this nascent science. Thus, despite the reputation

for impeccable logic which Dalton enjoyed, there were, soon, some serious challenges to his table of atomic weights.

Portrait of Joseph Louis Gay-Lussac, French physicist and chemist- Public Domain. François Séraphin Delpech - chemistryland.com

Source: https://en.wikipedia.org/wiki/Joseph_Louis_Gay-Lussac

The first challenge to Dalton's method came from some elegant experiments on combinations of gases, conducted mainly by Joseph Gay-Lussac. Whereas Dalton mainly used the weights of reacting elements to construct the formulae, and calculate atomic weights, Gay-Lussac (1778-1850) was studying the volumes of reacting gases. On the basis of numerous experiments, he arrived at the law of combining volumes: at a given pressure and temperature, gases combine in simple proportions by volume. If any of the products are gaseous, they also bear a simple whole number ratio to that of any gaseous reactant. For example, 2l of hydrogen combine with 1l of oxygen to give 2l of water vapour. The ratio of these volumes is 2:1:2.

The volume ratios for some reacting gases are given below:

Reaction	Volume Ratios for Reactants
Hydrogen + Oxygen → Water	2:1
Hydrogen + Chlorine → Hydrogen Chloride	1:1
Carbon Monoxide + Oxygen→ Carbon Dioxide	2:1
Methane + Oxygen → Water + Carbon Dioxide	1:2

Gay-Lussac did not infer anything from these results, although the conclusion was staring him in the face. If elements combine as atoms, and the volumes of combining gases bear a simple ratio, there must be some relationship between volume and the number of atoms.

Berzelius (1779-1848) interpreted Gay-Lussac's law to mean that equal volumes of gases, under identical conditions of temperature and pressure, have the same number of atoms. Since Dalton had already proposed the idea that simple whole numbers of atoms join together to give compounds, then if a given volume of hydrogen has, say 1000 atoms, it will combine with 1000 atoms of chlorine. Since this amount of chlorine occupies the same volume as hydrogen, it follows that under similar conditions of temperature and pressure, equal volumes of any gas will contain the same number of atoms.

Applied to the reaction of hydrogen and oxygen, the idea will appear thus

Hydrogen + oxygen → water

2 vol + 1 vol → 2 vol

2n particles + 1n particle → 2n particles

If we assume n to be equal to 10, Berzelius would conclude that 2 vol of hydrogen would contain 20 atoms of hydrogen, and 1 vol of oxygen would have 10 atoms of oxygen. Thus, according to Berzelius, the number of atoms of hydrogen and oxygen in water would be in the ratio of 2:1; the formula of water would thus be H2O (and not HO, as assumed by Dalton), and every atom of oxygen would be 16 times as heavy as a hydrogen atom.

Berzelius' interpretation provided a simple method to determine atomic weights: make various gases react separately with one volume of hydrogen, and measure the volume of gases which combine completely with one volume of hydrogen.

The contradiction

Dalton, obviously, had great doubts about Berzelius' conclusion, as it seemed to contradict the central postulate of his atomic theory, viz., the indivisibility of elemental atoms. Let us continue with the example of water to illustrate this point. We will start by writing the equation for dissociation of water vapour into its elements:

Water vapour → Hydrogen + Oxygen

2 vol	**→**	**2 vol**	**+**	**1 vol**
2 atoms	**→**	**2 atoms**	**+**	**1 atom**
1 atom	**→**	**1 atom**	**+**	**1/2 atom**

The problem is starkly clear – If one atom of water is dissociated (or inversely if one atom of water is created), one will get (or need) half an atom of oxygen; thus, Berzelius' proposal seemed to go against the indivisibility of atoms, and thus was unacceptable to Dalton.

The battlefield of atomic weights

Not just Dalton and Berzelius, many others too came up with their own ways of calculating and reporting atomic weights. They differed in their methods, experimental results, and units for comparison; among other things (for example Berzelius decided to assume the atomic weight of Oxygen to be 100). There was a time when it became impossible to read published research accounts due to the multiplicity of atomic weights and formulae based on the same. It is reported that acetic acid had something like 13 formulae. In this situation, many chemists stopped using atomic weights, and went back to reporting only combining weights. Some people, including leading chemists like Dumas and Wohler, even suggested abandoning the whole idea of atoms, as being too abstract and confusing.

A solution neglected for half a century

We may all have heard of the Italian chemist Amedeo Avogadro, for his hypothesis that replaced the word atom with molecule in Berzelius' proposal (which, if you do not remember, suggested that at a given pressure and temperature, all gases contain the same number of atoms). It almost appears that Avogadro was engaging in semantics. On the contrary, he was expressing something very profound about the nature of elements and chemical combinations, which was to revolutionise thinking in chemistry, in addition to solving the riddle of atomic weights, and the apparent contradiction between Gay-Lussac's results and Dalton's atomic theory.

So, what did Avogadro say, and why was it neglected for fifty years? In short, Avogadro proposed that elements can, and do often, exist as compound atoms. In his paper published in 1811, Avogadro hypothesized that the ultimate particles are of two kinds – atoms and molecules. His most 'preposterous' suggestion was that even elements could exist as molecules. On the basis of this, he

Picture of Amedeo Avogadro (1776–1856), the Italian scientist – *Public Domain. From a drawing by C. Sentier, executed in Torino at Litografia Doyen in 1856. Edgar Fahs Smith collection.*

was able to make the famous change, we now know as Avogadro's hypothesis: at a given temperature and pressure, all gases contain equal number of molecules (which may consist of more than one atom).

According to Avogadro, the above reaction between hydrogen and oxygen can be understood as follows:

Hydrogen + oxygen → water

2 vol + 1 vol → 2 vol

2n molecules + 1n molecules → 2n molecules

1 molecules + 1/2 molecules → 1 molecules

In effect, what he said was that both hydrogen and oxygen existed as molecules, and that these molecules contained two atoms each of their respective elements. Thus, in the last reaction, what was splitting was a molecule of oxygen, not an atom of the same element. This was in keeping with Dalton's theory. If one accepted this suggestion, things become a lot less complicated.

It is said that this seminal paper remained in oblivion for so long, because it was published in Italian, in an obscure journal, and Avogadro's presentation was very crude. However, to be fair to the chemists of the day, one must note that Avogadro had no theoretical basis for this

suggestion. It was common understanding during those days that elements react with each other because of their opposite charges. This made it difficult, if not impossible, to place the idea of atoms of the same element coming together to give you a molecule. This may be another reason for the neglect. It is obvious that instead of providing a new theoretical insight into the nature of matter, Avogadro's attempt was made to reconcile Dalton's theory and Berzilius' interpretation of Gay-Lussac's experimental results.

The idea of atomic weight was such a fundamental and practically useful idea that chemists were not willing to give it up, and go back to alchemic ways. Thus many other attempts were made to make this idea workable.

Other attempts

A) Dulong and Petit Method

One such method was proposed by Pierre Dulong (1789-1838) and Alexis Petit (1791-1820). In 1819, they discovered a relationship which could be stated in the form of a law: the atomic weight of a metal multiplied by its specific heat is approximately equal to 6.4.

Since the specific heat of a metal can be determined experimentally, this law can be used to find the approximate atomic weights of metals. At least it can be used to ascertain the correct value from among various competing values determined experimentally. Let us take a brief look at an example.

The approximate atomic weight of silver, calculated from its specific heat is 113.3. From an actual experiment involving reaction of weighed quantities of silver and oxygen, it was found that they react in the ratio of 13.51:1. If we assume that one atom of silver reacts with one atom of oxygen, this means that an atom of silver is 13.51 times as heavy as an oxygen atom. This gives a value of 216.16 (16×13.51) as the atomic weight of silver.

Using data on its specific heat, we have the approximate atomic weight of silver as 113.3, which is roughly half the weight obtained above. Hence, the formula of silver oxide is Ag_2O, and the atomic weight of silver is $216.16 / 2 = 108.08$.

B) Victor Meyer method

Victor Meyer basically refined existing techniques to find vapour densities, and applied Berzelius' method to compare atomic weights. He was able to extend the method to vapours, in addition to gases.

You can see the basic problem in determining atomic weights. While we make a measurement on macroscopic amounts of reactants, we want to draw some conclusions about the relative masses of individual atoms. Suppose, we have one box containing bananas weighing 500g and another box containing oranges weighing 1kg. With this data in hand, we can hardly compare weight of one banana and weight of an orange. However, if we assume that each of them contains a dozen of each fruit, then we may say that each orange is twice as heavy as a banana. With atoms, we cannot know, we can make only assumptions.

As was mentioned in the beginning, atomic weights are useful because they give us a way to understand and predict the course of chemical reactions.

From what has been said above, you can appreciate the confusion and turmoil the problem of atomic weight must have created in the first half of nineteenth century. One chemist, who was deeply concerned about this problem, was August Kekule. He called a conference of chemists from across nations to resolve just this riddle, as he felt that this continuing confusion will stall the progress of science. This first global conference of chemists was held in Karlsruhe (Germany) in 1860.

C) Enters Cannizzaro

The Karlsruhe conference should be seen as an effort to come to a consensus. It would have failed, had not a young school teacher, named Stanislav Canizzaro, intervened at the right moment.

Canizzaro's main contribution was to attract the attention of the conference participants to the 1811 paper by Avogadro and propose that it presented a neat method of determining atomic weights. The method is given here as it highlights the fact that the problem of atomic weights was resolved through application of logic and statesmanship.

Cannizzaro's method

In the conference, Stanislav Cannizzaro circulated a note in which he applied Avogadro's hypothesis to select the correct weights for the atoms of different elements. He postulated that:

- All atoms of any element have a definite weight.

- Since molecules, such as a hydrogen molecule or a water molecule, contain a definite numbers of atoms, they must have definite weights, which we refer to as formula weights.
- These formula weights contain one atomic weight (or a whole-number multiple of that atomic weight) for each element present.

Based on these postulates, he proposed a method to calculate atomic weights, following the steps given below:

- According to Avogadro, the molecular formula of water is H2O.
- If all gases have an equal number of molecules in equal volumes, their densities will be proportional to their molecular weights, i.e. M α D or M = kD, where k is a constant, M is the molecular weight, and D is the density of the given gas.
- If we know the molecular weight of a gas, we can calculate the constant k from its density. For example, hydrogen has a molecular weight of 2 and oxygen 32. Therefore:

Gas	Molecular weight	Density	k=M/D
Hydrogen	2	0.09	22.25
Oxygen	32	1.43	22.4

- Thus the average value of the constant k is 22.33 (average of 22.25 and 22.4)
- To calculate the atomic weights of carbon and chlorine, we have to find out the molecular weights of the various gaseous compounds of carbon and chlorine, from their densities.(by applying M=kD)

Compound	Density g/l	Molecular weight (M=kD)	Weight percentage			Amount in one molecule (calculated from molecular weight and experimental data)			Probable formula
			Carbon	Hydrogen	Chlorine	Carbon	Hydrogen	Chlorine	
Methane	0.715	16.0	74.8	25	-	12	4.03	-	CH_4
Ethane	1.340	29.9	79.8	20	-	23.9	6.04	-	C_2H_6
Ethyl chloride	2.88	64.3	37.2	7.8	55	23.9	5.02	35.04	C_2H_5Cl
Chloroform	5.34	119.1	10.05	0.85	89.1	12.2	1.01	106.2	$CHCl_3$
Carbon tetrachloride	6.83	152.6	7.8	-	92.9	11.01	-	141	CCl_4

- Let us see how the above information is derived from data. Step 4 (of applying the equation M=kD) gives 16 as the molecular weight of methane. The percentage of carbon in methane (column 2) is 74.8. That is, 100g of methane has 74.8g of carbon. Therefore, 16g of methane (one mole of methane) contains (74.8/100) × 16 = 12g of carbon. The other values in the table have been calculated in a similar manner.
- We have calculated the amount of every element in one mole of each of the compounds. Next, we look at the minimum amount of an element present in these compounds. We can see that one mole of each compound has different amounts of carbon. The minimum amount of carbon in one mole of its compounds is 12g. From this, we take the atomic weight of carbon as 12 because we assume that these compounds contain at least one atom of carbon. If later studies give us compounds whose 1 mole contains 6g or 4g of carbon, we will have to revise the atomic weight of carbon. Till then, the atomic weight of carbon can be taken as 12.
- Likewise the atomic weights of other elements can be calculated.

Further developments

With the Karlsruhe Conference, the matter seemed to have been settled. However, the discovery of isotopes provided a new set of challenges to the idea of a unique atomic weight for each element. They led to the idea of elements having fractional atomic weights.

Recently the International Union of Pure and Applied Chemists have had to deal with another problem. It was found that atomic weights of some elements differ according to where and how the element is obtained. This had to with differing isotopic compositions of elements in different places and environments. The suggested solution for this is that from now onwards, atomic weights will be reported as a range rather than as a single value.

We are not going into the details of all these developments, but it must be clear, by now, that the atomic weights reported in the periodic table we have all been using, have not been easy to arrive at. Ultimately, it was the actual process of counting atoms and molecules (Avogadro number) that has given us the answer that we think of as the final one, today. But is this the last we'll hear of this?

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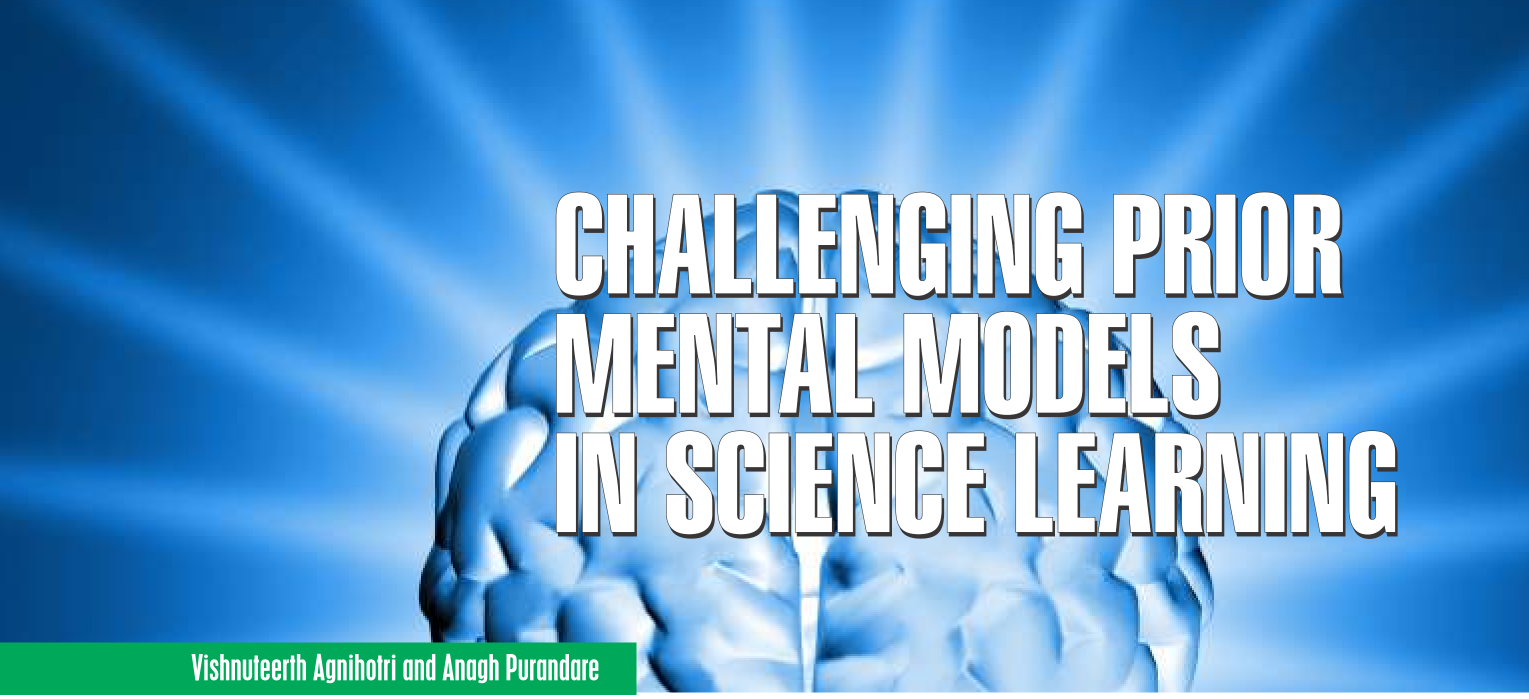
__Uma Sudhir__ has done her Ph.D. in Chemistry, and has a degree in Education. She has been associated with Eklavya for last 12 years, and has contributed to developing science teaching-learning material and training teachers in teaching science with a critical pedagogy.



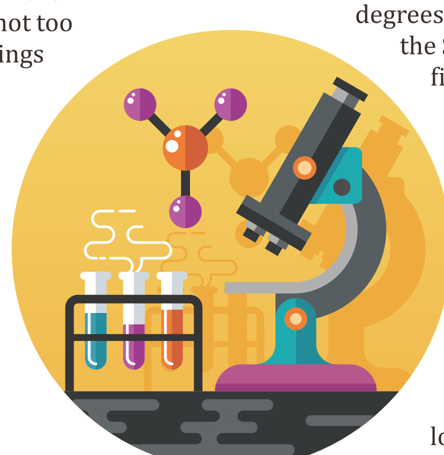
CHALLENGING PRIOR MENTAL MODELS IN SCIENCE LEARNING

Vishnuteerth Agnihotri and Anagh Purandare

Are all that children surmise from their day-to-day experiences, actual scientific truth? In this article, we discuss three examples that show how children have such 'prior mental models' before they enter classrooms, and how these could persist, even into adulthood. We also discuss potential ways to help learners replace these 'prior mental models' with correct scientific models.

Introduction

Observations of the world around us are very important for learning. A two year old, to our great consternation, may learn that food always falls down by repeatedly throwing it up; our own mature selves may learn that dosa will not stick to the pan if the temperature is high enough, but not too high. These common-sense learnings are very useful and often even critical for survival, but are such learnings gathered from observations and common sense, scientific facts? Let us examine these by exploring some everyday phenomena.



Example 1

A metal coin is colder than a wooden spoon in the same room.

We bet many of you think the metal coin is colder - you certainly don't want some prankster slipping a metal coin down your shirt on a cold winter day! But in fact, the metal coin and the wooden spoon are at the same temperature (unless one of them is being heated, or has been put in the refrigerator, or has just been brought in from outside). How could that be? After all, the metal coin feels so much colder to touch than the wooden spoon!

Here's a hint as to why this might be happening - if you were in a room at 55 degrees Celsius somewhere in the Sahara desert, you would find the metal coin hotter than the wooden spoon.

What is happening here is that human beings do not make very good thermometers - when we touch a metal coin, heat gets conducted away from our body to the coin at a faster rate (as compared to wood which is a poorer conductor), and it is this loss of heat we sense as 'cold'. If you use a thermometer, you will find that both are actually at the same temperature.

This is a common misconception - 86% of class 8 students* think that a metal spoon would be hotter than a wooden spoon after both of them have been in hot water for half a day.

* *The data is based on ASSET, a diagnostic test from Educational Initiatives.* http://www.ei-india.com/asset/

A metal spoon, a wooden spoon and a plastic spoon are placed in hot water for half a day. The water is maintained at the same temperature throughout.

At the end of the experiment, the objects are taken out and their temperature is measured immediately. Which of the following is likely to have the highest temperature?

Option	Option	Performance
A	the metal spoon	86.4%
B	the plastic spoon	4.2%
C	the wooden spoon	3.9%
D	(All the three spoons will have almost the same temperature.)	5.2%

Also check out a very interesting video at https://youtu.be/vqDbMEdLiCs , where a researcher tries this 'trick' on various people, and explains what is happening.

Example 2

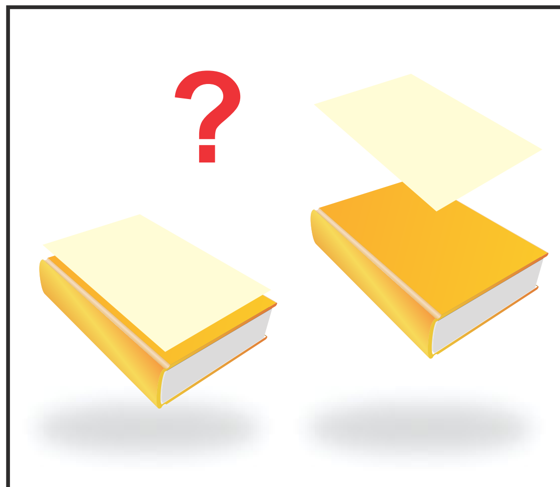
We can see things in the dark if we wait for some time.

You are in a room which is completely dark - do you think you will be able to see a chair in front of you after a few seconds? Again, when you are asked this question, you might recall that whenever you have entered a dark room, you have not been able to see anything immediately, but after a few minutes, your eyes have adjusted to the light in the room, and you start to see a few things at least. Right? So you might answer "yes- I will see the chair after a while". But what if the room is completely dark? If there is no light entering the room, then however much time we might spend in the room, we will not see anything, because to see anything, we need some light reflected from the object to enter our eyes. In our daily experience, we never experience a completely dark room (there is always some light trickling into any room - maybe moonlight or from a street lamp) and therefore, we tend to assume that if we wait long enough, we would be able to see things in the dark, at least dimly.

Example 3

A heavier object always falls faster than a lighter object

Suppose you are holding a heavy brick in one hand, and a small book in the other (taped so that it won't open up), and are standing on the 3rd floor of a building. If you release both of them at the same time, which of these is likely to hit the ground first? It may be hard for you to try this now, so let's try another one - what do you think would happen if you place a sheet of paper on top of a book you are holding, and drop the book (tape the book so that it doesn't 'open out')? Do you expect them to fall together, or do you expect the paper to 'stay back' and fall slower to the ground? Answer this question, and verify your answer by actually trying this out before you read further... What did you find? Surprised?



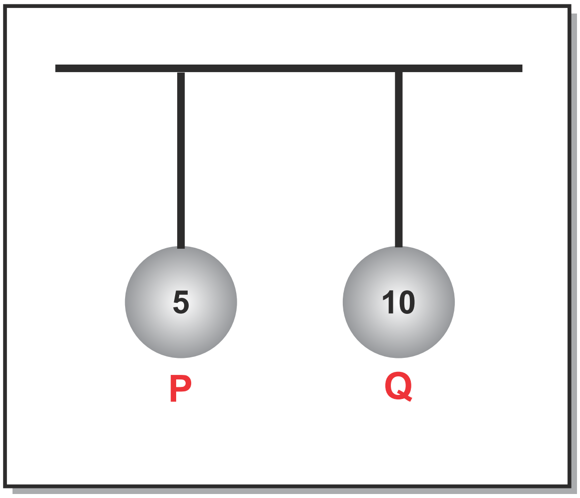
Will the book & paper fall together? Will the paper fall slower?

We have tried the above three questions (among many others) with several students, teachers and intelligent adults over the years, and most are surprised at what they find - the metal coin and the wooden spoon being at the same temperature, not being able to see in the dark, or heavier objects falling at the same rate as lighter ones.

For example, look at another ASSET* question below, almost half of the class 9 students think that the heavier ball will fall to the ground faster:

Two balls, P and Q of equal size but unequal mass (P weighs 5 kg and Q weighs 10 kg), are hanging from strings as shown in the diagram. The strings are simultaneously cut. Which of them would fall to the ground faster and why?

** The data is based on ASSET, a diagnostic test from Educational Initiatives.* http://www.ei-india.com/asset/

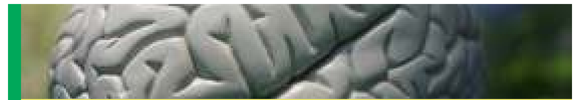


Option	Option	Performance
A	Q will fall faster than P because heavier objects always fall faster to the ground	43.7%
B	P will fall faster than Q because lighter objects always fall faster to the ground	6.9%
C	Both will take the same time because the time taken to fall does not depend on the weight	41.9%
D	We cannot say because it depends on the height from which they are falling	6.6%

Why does this happen? Often, we have learnt the science behind the phenomenon - why is it still so hard? Let us examine this by going into more detail.

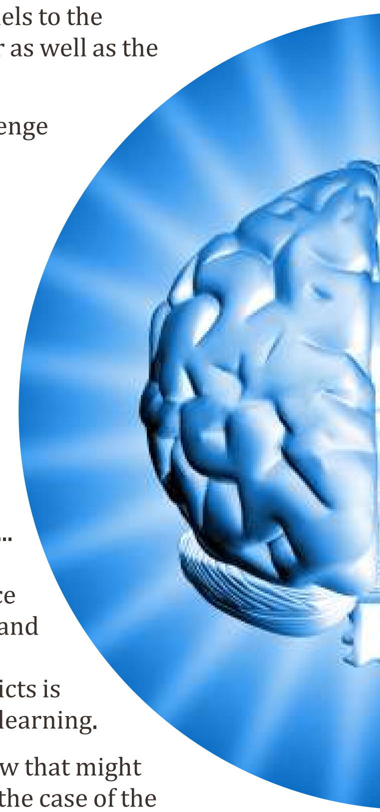
Why do we continue to believe that heavier objects fall faster than lighter objects, even though we might have read that they fall at the same rate or even solved many problems using equations that show they do? This probably happens because we do not grasp the idea of air resistance - air being invisible, seeing the slow drifting fall of a leaf or a feather, we may interpret such observations to form the idea (or 'mental model') that 'lighter objects fall slower'. Even if we understand the idea of air resistance (which older children or adults do), we may still be wrongly extrapolating the idea that heavier objects experience a higher gravitational pull to conclude that they would also fall at a faster rate. It is quite 'intuitive' to think that a heavier object will fall faster than a lighter object and not entirely wrong - it is just a limited idea that applies only in special cases, and is certainly not a general scientific principle.

One of the main drawbacks of traditional science teaching is that it does not recognise that students come to the classroom with "prior mental models", and that the process of teaching-learning, requires:

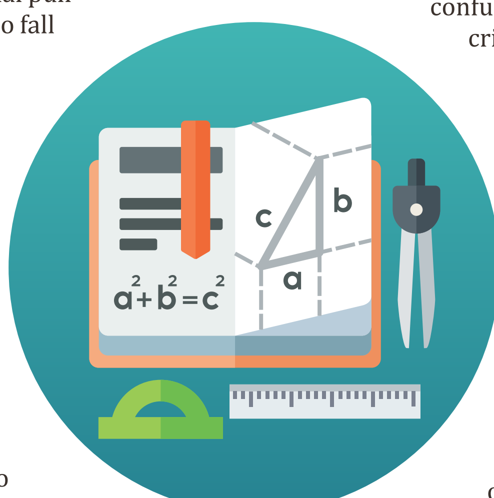


"Scientific ideas are, with rare exceptions, counter-intuitive: they cannot be acquired by simple inspection of phenomena and are often outside everyday experience."
- Lewis Wolpert, The unnatural nature of science

- Bringing such mental models to the surface, so that the learner as well as the teacher are aware of these
- Devising methods to challenge these mental models
- Discussions and exercises that allow the learner to replace her prior, incorrect, mental models with correct scientific ones.



But, more often than not, neither the teacher nor the learner is aware of these mental models, and everything may appear to be clearly understood... till you face a situation of 'cognitive conflict'. A good science teacher knows that recognizing and working through the confusion and conflicts is critical for deep learning.



Let us see how that might play out in the case of the falling objects. First, a teacher may create a cognitive conflict by asking students to do the experiment with the 'paper on the book' described above. That might perhaps alert students to the existence of air resistance and create sufficient doubts in their mind on what was previously self-

* The data is based on ASSET, a diagnostic test from Educational Initiatives. http://www.ei-india.com/asset/

evident to them (that heavier objects fall faster). Now a teacher might help students to think through all factors that might play a role in the process - through a discussion, students might identify factors like - surface area, hollowness, roughness, windiness of conditions etc. Having done this, students would then perform a variety of experiments with different objects till they come to a deep conclusion based on these that lighter objects do indeed fall at the same rate as heavier objects.

But does that 1% doubt still linger in your mind about whether a feather would reach the ground at the same time as a heavy bowling ball if air resistance were not present? What would it take to be 100% sure - the only way is to drop these objects in a vacuum environment - where would you find one! Fortunately for us, this expensive experiment has been done - watch the amazing clip below from BBC's Human Universe series and can be accessed here - https://youtu.be/E43-CfukEgs.

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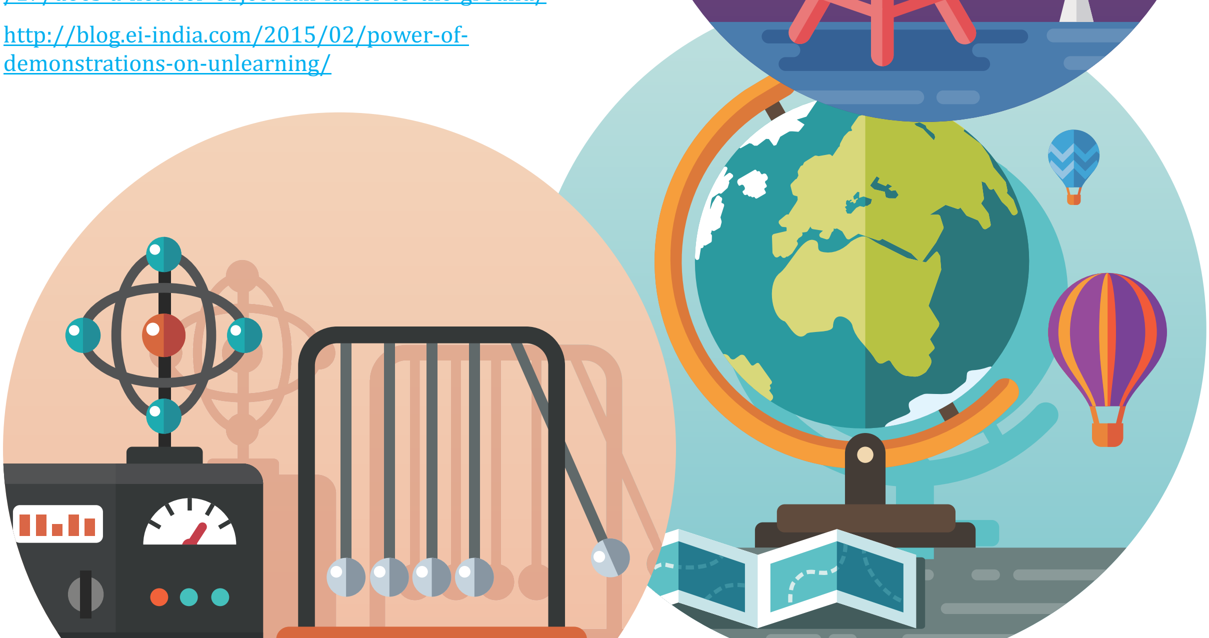
You can also visit our blog posts that discuss one of the above examples in details:

https://tostudentandteacher.wordpress.com/2015/01/17/does-a-heavier-object-fall-faster-to-the-ground/

http://blog.ei-india.com/2015/02/power-of-demonstrations-on-unlearning/



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THE OVERCAST SKY

Asif Akhtar

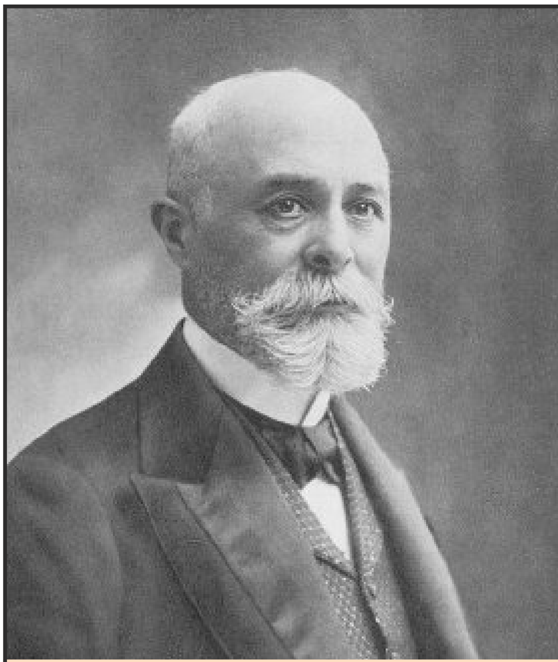
How did bad weather and a chance observation of what was most likely a failed experiment, lead to the Nobel-prize winning discovery of radioactivity? In this article, the author narrates the story of Henri Becquerel's experiments with uranium salts, describing a series of scientific investigations that arose to understand an unexpected and unusual observation, originally made by this physicist.

It was the first of March 1896, and a lazy winter day in Paris. The sun hadn't come out of the clouds once in the last four days.

The physicist Henri Becquerel, working in his laboratory, knew that on such a cloudy day, he would not be able to get any results in his on-going study. For the last few months, he had been studying the properties of phosphorescent compounds using photographic plates that were exposed to sunlight. On a sunless day, like this one, his photographic plates would remain un-exposed.

This was around the time when X-rays, discovered by Wilhelm Conrad Rontgen, were a popular subject of research in the global scientific community. The first X-rays to be detected had been accompanied by a form of phosphorescence in vaccum tubes. Henri was interested in investigating whether X-rays were in any way connected to naturally occurring phosphorescence. He hypothesised that to emit a penetrating radiation, like X-rays, a body had to luminesce.

To prove this, Henri had planned a series of experiments where he would first expose a



A portrait of Antoine Henri Becquerel.
Image Courtesy: Paul Nadar. Repository: Smithsonian Institution Libraries. Accessed on: Wikimedia Commons. License: Public Domain. URL: https://en.wikipedia.org/wiki/File:Portrait_of_Antoine-Henri_Becquerel.jpg

Wilhelm Conrad Rontgen

phosphorescent compound to sunlight by leaving it on a window-sill in his laboratory, and then, place this compound along with a metal object over an unexposed photographic plate, covering the entire apparatus with an opaque paper. The apparatus would be left in a dark bureau drawer in his laboratory overnight.

If the compound being tested was indeed luminescent, exposure to sunlight would make it glow. Exposed to this glow, an image of the metal object would be developed on the photographic plates. This glow, according to Becquerel, would suggest that the phosphorescent compound was emitting X-rays.

Henri chose to conduct his first few experiments using a supply of uranium salts that he had inherited from his father, Edmond Becquerel, also a physicist like Henri, and a leading expert of his times on the phosphorescence of solids. Although Uranium had been discovered in 1789 by the German chemist, Martin Klaproth, it was mainly used in making coloured glazes and glass, and had not received significant attention in the scientific community. In 1869, when Dmitrii Mendeleev, a chemist, placed it as the heaviest element in his version of the periodic table, where he arranged elements in order of increasing atomic weights, there was renewed interest in this element. Edmund Becquerel had studied sulphides and other compounds of uranium extensively, due to their exceptionally bright phosphorescence.

On the day our story begins, Henri Becquerel decided to develop all the photographic plates with uranium crystals that he had prepared in the previous week. Due to the wintry overcast skies in Paris, none of these had received much sunlight, and Henri did not expect to see much on his plates.

Why he chose to still develop these plates has been a subject of a lot of speculation ever since. Some of the most common reasons suggested include Henri's over-riding curiousity; or, his natural sense of thrift – he would be reluctant to simply throw away the photographic plates that he had used so carefully in setting up his experiment. Another reason that is often suggested is that Henri was scheduled to attend an important meeting in the next week, and hoped that even results from his failed experiments would be better than having nothing

Photographic plate made by Henri Becquerel showing effects of exposure to radioactivity.
Contributor: Ranveig. Accessed on: Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Becquerel_plate.jpg

to show. The real reason for Henri's actions will probably always remain a mystery.

What is known, however, is that while he developed his plates, Henri expected to see some very light images on them, seen sometimes with phosphorescent substances exposed to very little light.

To his complete surprise, however, not only were his plates exposed, he could see some very bright images on them. This was completely unexpected. There had been no source of light in the dark drawer. Without being exposed to enough light how had the clear dark images appeared on his photographic plates?

The salt which had resulted in these images on his photographic plates was potassium uranyl sulphate K2 U O2 (So4). Henri repeated his experiment with these crystals, more than once, and found the same results each time. His photographic plates showed clear dark images even when the crystals were exposed to little light.

Henri wasted no time in sending a report of his findings to the Academy of Sciences in Paris. In this report, Henri concluded that the images he was seeing were formed because potassium uranyl sulphate crystals could be stimulated by diffused sunlight, as well as reflected and refracted sunlight. He also suggested that when stimulated in this way, the uranium crystals were capable of producing radiations, which in all probability, were X-rays.

This discovery was received with great interest by the scientific community, and was widely repeated across the world – always resulting in similar images being produced by uranium salts, exposed to poor light, on photographic plates. However, it also seemed clear that though some of the energy produced by the stimulated uranium crystals were in form of X-ray-like pulses of light, these X-rays did not seem sufficient to account for the intensity of images on photographic plates, or the ability of these crystals to be able to ionise gases, or sometimes even burn physicists attempting to replicating Henri's experiment. Was this a reflection of how strongly the uranium crystals had been stimulated?

In his next set of experiments, Henri tried to determine if any light at all was needed to stimulate the uranium crystals. He did this by using the same method as before, except that the crystals used in this set were not exposed to sunlight, and the experiment was conducted in a dark room. The crystals were placed on photographic plates in an opaque cardboard box. In some of these trials, crystals were also separated from the emulsion using aluminium and glass sheets. In each case, the same results were obtained, showing that uranium crystals did not need to be exposed to light immediately before they were used to develop photographic plates, and that the images that were being seen on photographic plates were not simply the result of a chemical reaction between the crystals and the plate. This led Henri to conclude that uranium crystals did not need to be stimulated immediately before an experiment. And that they were able to produce invisible radiations that could persist for longer periods than luminous rays emitted by these compounds. However, he continued to incorrectly assume that this property was related to the phosphorescence of the uranium crystals.

He was therefore at a loss to explain why such equally intense images were found to be produced by non-phosphorescent salts like uranous sulphate. Was it possible that the ability to produce intense invisible radiations had little to do with phosphorescence, and everything to do

with the nature of the potassium uranyl sulphate crystals Henri had been using in his experiments? To explore this possibility, Henri decided to investigate crystals of uranium nitrate in his next set of experiments. Uranium nitrate is known to lose luminescence when dissolved or melted in the water of its crystallisation. So Henri heated uranium nitrate crystal in darkness, protecting it using a glass tube from even the light of the alcohol flame. This compound was then allowed to recrystallize in the darkness. Heating had destroyed phosphorescence of this salt.

If Henri had been correct in assuming that only phosphorescent compounds could produce invisible radiations, these newly crystallised uranium nitrate salts should have been incapable of producing the images seen on photographic plates with uranium sulphate. However, when this experiment was conducted, the clarity of the images produced remained unaffected.

His experiments led Henri to conclude that these invisible radiations that helped develop photographic plates were not a general property of all phosphorescent compounds, but instead specific to salts of uranium. That they were produced by uranium atoms was finally proved in May 1896, when Henri showed that on using pure uranium metal, the radiations produced were 3-4 times as intense as those produced with uranyl sulphate.

This phenomenon was named radioactivity by Marie Curie. Along with her husband Pierre Curie, Marie continued her intense research on the properties of these invisible rays. Henri, Marie and Pierre were jointly awarded Nobel Prize in 1903 in Physics.

The initial observation that led Henri to this path of discovery is now celebrated as an example of serendipity, or an accidental discovery. But, like any other such accidental discovery, Henri's ability to recognise that the dark images he was seeing on his plates were only possible if the plates had been exposed continuously to an intense source of light, and in the absence of any such known source of light in his experiment, this result was unusual; shows that this discovery was also dependent on Henri's scientific aptitude. Not just that – subsequent to his initial observation, Henri's numerous experiments, often along many false trails, finally resulting in a better and more accurate understanding of the phenomenon of radioactivity, is a testament to the hard work and perseverance involved in this discovery.

In the last 119 years, these invisible radiations have been recognised as both a boon and a curse. On the one hand, this phenomenon has resulted in the production of a large source of energy in the form of electricity; and has been used to save the lives of hundreds of thousands of cancer patients. While, on the other hand, it has helped produce nuclear weapons capable enough to annihilate mankind from planet Earth.

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THE LITTLE-KNOWN WORLD OF FLIES!

Geetha Iyer

What makes flies different from a dragonfly or a butterfly? How do the lovely iridescent bluebottle and greenbottle flies help solve murders? What do insect bites, galls and chocolate have in common? Do flies have taste-buds? How do we introduce flies in science classrooms? This article explores the fascinating world of true flies, their incredible variety, and the diversity of services they provide us with, ending with an activity that teachers can use to unravel one aspect of the life of flies to students.

Introduction

"To know the fly is to share a bit in the sublimity of Knowledge." - Prof Vincent G Dethier

Flies generally conjure a vision of dirt, disease and disgust.

Our introduction to this image of flies is in school. A student is introduced to the humble housefly in a conclusive manner, leaving one with the impression that all flies are repulsive creatures. Limited scientific information about houseflies is accompanied by a vivid description of the mouth parts being used to drink from muck, thereby leaving an indelible image of a fly only as a vermin. A student's next encounter with the fly is during a lesson on health, as the carrier of diseases, thereby nailing the coffin on the possibility of flies being anything but loathsome creatures.

No doubt there are many flies that bite and spread disease. *But do all flies deserve such an image?* It's time someone spoke up for flies, whose colour, variety and elegance should not be judged only by the housefly, or the behaviour restricted to a frolic in decomposing heaps, although this frolic is not

Brown Muscid Fly

without benefit, and I shall soon tell you how and why.

Although there are many interesting aspects of flies that one can dwell on in this article I will confine myself to introducing you to a small group one can chance upon even in urban environments; and to the diversity and services some flies in this order perform. I shall conclude with how the mouth parts of a housefly can be observed in a manner that is more interesting than looking at a slide with artificial colours under a microscope.

Are flies filthy?

Flies are among the cleanest of insects, and are very particular about their own hygiene. In fact, humans could take a lesson or two on personal hygiene from them. Observe a fly closely next time, and you will notice how frequently it cleans itself.

If a fly does visit decomposing materials for its nutrient requirements, it does so to satisfy its nutritional needs. After all we humans too like food growing on decomposing matter, don't we? If you were to take a survey of your daily intake of food, you'd be surprised by *how many* of our favourite foods come from decomposing matter! Take mushrooms, for example, that grow so very well on cow dung; or Kombucha, a health drink, made by allowing certain yeast and bacterial species (kombucha culture appearing like a slimy pancake) to grow in a sugary solution of black or green tea! What a variety of fermenting food items we consume!

Perhaps, some of the blame for the diseases that flies transmit lies in humans too! If we gave more thought to our hygiene and sanitation, flies wouldn't frequent our environment so freely, would they?

What is a fly?

In a world populated by the Butterfly, Dragonfly, Scorpion fly, Mayfly, Stonefly, Firefly, Owlfly, and so on, what is this insect that is simply called a fly?

The insects listed above are not flies from an entomologists' point of view. True flies are insects that belong to the order Diptera, a name that describes their defining feature – these flies have only one pair of wings (in Latin, *di*: means two, and *ptera*: means wings). In contrast, insects belonging to all other insect orders have two pairs of wings! What makes this even more interesting is that true flies have evolved from four-winged ancestors in the Permian 250MYA (million years ago). In their modern-day descendants, however, this second pair - the hindwings - has become reduced to club-shaped structures, called Halteres. Each haltere can be likened to a gyroscope; they are essential in maintaining balance during flight.

Chrysops sp. **Biting fly.**

Two wings seem to have made them no less agile than other insects, eminently deserving the name "fly"! Consider these facts, not learnt in a class on flies. Flies are incredibly nimble in flight. The best aerialists among insects, they can hover, fly backwards, turn in place and fly upside down to land on the ceiling! They have sensors - speed indicators - located in a part of their antenna called arista, to gauge their flight speed. A housefly's wing speed is about 190 beats in a single second! The fastest muscular contraction a human being can manage clocks at ten times per second. No mystery then, why it is so difficult to swat a fly!

How many flies are there in the world?

No one knows an exact number. As mentioned before, true flies belong to the order Diptera, which is the third largest group among insects. Mosquitoes belong to this order too! More than 1,60,000 species of flies have already been described by specialists; with very many more yet to be classified, and several more to be discovered. As you can tell, this means a very large number, indeed!

Fly Services and Diversity

Every family of animals (including humans) on this planet, have their share of villains and heroes; and, fly families are no exception! There are many

interesting things one can learn by exploring the world of flies. I shall describe a handful of these here.

A. Flies as Pollinators: It is a well-established fact that plants and insects have mutually influenced the evolution of their diversity. Flies are believed to be foremost amongst the pollinators of early flowering plants; yet their role in such an important service remains relatively unknown. Of the 150 dipteran families, fly species of nearly 70 families (Evenhuis et al. 2008) are known to visit flowers to feed. It has been documented that flies are the primary pollinators for several hundreds of wild or cultivated plants (close to 550, according to Larsen et al. 2001). Pollination by flies is, generally, referred to as myophily.

What makes flies such good pollinators? They are not only abundant, but are also present in widely diverse habitats. They are the most important pollinators in alpine or arctic regions, where pollination by bees is reduced. In the under-storey regions of forests, flies are believed to be important in pollinating a wide variety of shrubs with small, inconspicuous or dioecious flowers. Their abundant presence is complimented by anatomical features, such as variations in mouth parts, tongue length, size and degree of pilosity (hairiness); all of which contribute to making flies some of the most effective pollinators, ever. Plants would probably nod their (flower) heads in agreement!

Flies visit flowers for their own reasons: nectar and pollen are sources of food. The proteins in pollen are necessary for some flies to reproduce. Some flies visit flowers to lay their eggs, ensuring that their developing larvae have easy access to food – the flower heads, seeds or developing fruits. And, so, for some flies, flowers are mating (dating?) sites. How convenient!

My favourite among these pollinators, without doubt, would be the beautiful and colourful flies of the Family Syrphidae, commonly called hover flies or flower flies. At first glance, a hoverfly would hardly strike one as a fly, looking more like a bee, than a fly. Each of them, however, has such a long proboscis, that it can go into the deepest of corollas to sip nectar. This makes them excellent pollinators, serving a wide range of plants, and second only to bees in this role. A large number of foods we consume are pollinated by hover flies. Look for these flies amongst the flowers of mango, apple, pear, cherry, and strawberry; or among coriander, onion, carrot, pepper, and capsicum, to name a few.

The life of an insect is full of tricks and treats that contribute to its survival. One such feature is the differing food source for larvae and adults. Adult insects don't compete with their young ones for food. Thus, while the adult hover fly is a vegetarian helping with pollination; it's larvae or maggots are insectivorous, feeding on a wide range of prey - mostly aphids and other sap sucking insects, and thereby acting as pest control agents - another fact about flies that rarely receives any attention. Thus, syrphid flies are important as pollinators and pest controllers.

Hover fly *Mesembrius quadrivittatus.*

Plants put out a variety of odours to attract insects. The putrid smell of decaying flesh from some flowers attracts carrion and dung flies, belonging to the Family Calliphoridae. They visit these flowers, expecting to find decaying flesh and, pollinate them, even as they leave disappointed. Commonly called blow flies, the bluebottle and greenbottle flies are quite colourful and attractive. Interestingly, they play an important role in forensics (see below).

Blow fly-Blue bottle fly, *Calliphora sp.*

Blowfly – Greenbottle, *Lucilla sp.*

Golden blowfly.

Robustly, built flies of the family Tabanidae, commonly called horse flies, or, simply, tabanid flies, are mostly bloodthirsty flies; but some of them are lesser fiends. They are considered pests, since many species bite animals and humans. But, some, with their spectacularly long tongues pollinate flowers that have long tube-shaped corollas (image Tabanid fly –*Philoliche sp.*). In the females of certain Philoliche species, the very long tongue is adapted to perform the dual functions of blood sucking and nectar sipping! Rhino-myophily is the term that describes pollination by long-tongued flies.

Tabanid fly - ***Philoliche spp.*** *Photo by Sanjay Sondhi*

Tabanid fly - ***Philoliche sp.*** *Photo by Sanjay Sondhi*

That universally loved food - chocolate, owes its existence to flies! Midges are flies. Those belonging to the families Ceratopogonidae and Cecidomyiidae, are known more for their biting and gall-forming habits than for anything applaudable. But, not all of them are biters or gallers! The cocoa plant relies on small midge species of these two families to pollinate its tiny white blossoms, produced on the lower parts of its main trunk. The mushroomish odour of the flower attracts midges, just as chocolates attract us. Other than a particular species of hover flies in some restricted regions, cocoa plants need midges to produce fruit. No midge, no cocoa, no chocolates! Do I hear shouts of three cheers for midges? Do remember to thank flies, the next time you feast on chocolates or cocoa.

A midge

B. Flies in Forensics: From the living to the dead, from flowers to corpses - as flies search for nutrition, their actions bestow indirect assistance to other living organisms. Flies help humans in criminal investigations, and are a favourite with forensic entomologists.

Blowflies are not just pollinators; their love for decomposing animal matter draws them to the dead. In fact, they are the first to arrive at a death

scene! So acute is its sense of smell, that a blow fly can apparently smell a dead body 16 km away! Members of this family are known by various names – bluebottles, greenbottles. They are easily recognised - looking like a larger version of the common housefly. Why are they drawn to dead bodies, one may ask? Blow flies look at dead bodies as a food source for their young ones. They lay their eggs in the orifices of corpses, and maggots hatch out in 24 hours. Flesh flies, of the Family Sarcophagidae, give birth to live young ones on the flesh of the corpses! How does this behaviour help us? The life history of a blow fly is well-documented, providing a mine of information during post-mortems of the corpses that attract them.

Flesh Fly

Other species of flies, such as the black soldier fly, the coffin fly, the black scavenger fly, members of Hydrotea sp. of Family Muscidae, and humpbacked flies, are equally useful in providing important information during autopsies. Their services range from determining whether the corpse has been moved from the original scene of crime, information about toxicology, and, in many cases, even in fixing the time of death.

"The Washing Away of Wrongs" written in 1247 AD by Sung Tz'u, a crime investigator in China, is the first record of flies in criminal investigation. This book is the first to lay the foundations of forensic entomology. A murder happens in a Chinese village, and the dead man's body is discovered, cut up badly. Unable to make any headway with his investigation, the investigator asks all the villagers to bring their sickles, and lay it on the ground in front of him. Soon flies swarm to one sickle. The owner had not washed his sickle well, and the flies were attracted to the odour of blood. The owner confesses to the crime, and, so, began the use of flies to solve crimes.

If you are a fan of the TV serial "Bones", then, surely, you must already be aware of the nuances of forensic entomology, from the work of the character Jack Hodgins, a forensic entomologist-cum-botanist.

There are many other such interesting instances of crimes, solved with the help of flies.

C. Flies as Pest Control Agents: Agricultural researchers and pragmatic farmers will vouch for the services provided by flies in keeping a check on phytophagous insects. There are many flies that help in these roles, but described below are a few favourites of mine.

I call them Jewel flies, and not long-legged flies, as they are more commonly called. Their more common name points to their long legs, a striking feature of the flies of the family Dolichopodidae. Jewel flies are slender and dainty little flies, sporting beautiful colours. Mostly blue, green, and gold with a metallic shine, there are a few of these ecologically important flies that sport a dull grey colour too. Looking very much like a fly on stilts; you cannot miss them. They have a slender body, prominent eyes, and their trademark long legs. Males show off their long legs to attract females; quite the opposite of the human species it would seem! Lavish manoeuvres and signals mark the courtship behaviour of males. Many of these flies mate in flight, which is an exhausting practice; so, sometimes males create an illusion by sporting a pattern to con the females into thinking that they are mating in flight.

Found in most habitats, Jewel flies are predatory, feeding on a wide variety of invertebrates - aphids, thrips, spider mites, and collembolans. In fact, a particular species of Dolichopus preys on mosquito larvae! Some species are scavengers too. These flies are fidgety; so one has to be really still and silent to watch them.

A long-legged fly

Long-legged flies

Soldiers and Robbers performing similar functions could happen only in the world of insects! Soldier flies belong to the family Stratiomyidae whereas the robber flies, to Family Asilidae. In the world of flies, the robbers attack and catch pests more often than the soldiers; the latter's services are varied and include some predation.

Robber flies are the most predatory group in the world of flies, and feed exclusively on insects. Their name is truly representative of their behaviour. They are aggressive hunters, ambush their prey, and are strongly built with powerful muscles that help them capture insects in flight! They are robbers in appearance too, sporting a tuft of stiff bristles - like a moustache - between their eyes, that are mounted prominently on their head. In fact, the term 'mystax' used to describe these bristles is derived from the Greek word meaning 'moustache' or 'upper lip'. These cosmopolitan flies enjoy a worldwide distribution, but are common in tropical and subtropical areas, and abundant in dry and sunny arid or semi-arid zones.

Robber flies can very easily be identified by their long slender bodies, with the tips of their abdomens visible beyond the folded wings. The mystax is unmistakable, and the head and thorax is hairy. Because of their long tapering abdomen, combined with brightly coloured – black, grey, red or yellow -patterns, they are often mistaken for wasps. Some of them with stout, hairy bodies, mimic bees; while others with slender, lithe bodies, imitate damselflies. As you can see, these robbers have mastered the art of disguise too! Their perch is another way of identifying these flies in a habitat. Robbers like to perch on the topmost end of a plant waiting to seize prey.

Robbers inject captured prey with saliva containing neurotoxic and proteolytic enzymes, killing them. Both adult and juvenile robber flies prey on a wide variety of insects, thus serving the important ecological function of keeping a check on the insect fauna in any area.

Mating Robber Flies

Green Soldier Fly

Soldier Fly

Soldier flies are diverse in their habits and food preferences, but are mainly recognised by their unique wing venation. Some soldiers are pollinators; some assist with forensics; others are helpful in composting waste; while a few of them are predatory. The brightly coloured ones resemble wasps and bees. Soldiers may be saprophagus, myophagous or predatory; and are generally found close to aquatic habitats in which their larvae develop. These flies are not a widely researched group, except Hermetia illucens, which is commonly called the black soldier fly. We shall look at this fly again, in the next section.

Small Soldier Fly

D. Flies in Composting: The black soldier fly, *Hermetia illucens*, is now being extensively used to compost wastes. However, this process is yet to find wider application in India, and is currently being practised only by a few researchers in Pune.

Crane Fly

The compost pit in my backyard has black soldier flies. The photo given here is of one of them helping decompose waste, along with other organisms.

Black Soldier Fly

E. Flies in Scientific Research: Fruit flies have been in our laboratories for decades now, and continue to play a well-known and extensively documented role in our efforts to understand gene action and inheritance mechanisms.

What is less well-known is the role of flies in some other kinds of experiments. In 2007, for example, some researchers at Harvard University built a robotic fly. Weighing 60mg, and with a wingspan of 3cm, this life-like fly was modelled to imitate the movements of a real fly. Made of ultra-thin carbon fibre, the robotic fly has a wing beat of 110 beats/second. This effort is the first step to

building flying insects that can be mounted with sensors, to function as spies. 'Fly on the wall' will soon become a reality, and not just be a fancy idiom, or so it seems. Army laboratories have definitely shown a great interest in these fly spies.

F. Flies and Soil Fertility: Imagine an oversized mosquito - that is what a Crane fly or Tipulid fly, belonging to the family Tipulidae, looks like. But, the similarity ends with their appearance. These gentle flies not only do not bite; adults do not feed at all! Adult flies live for about 10 to 15 days. Females emerge from their pupa with mature ova. They seek out mates, and soon after, lay their eggs on moist soil, or sometimes, on the surface of water. As they feed, their larvae help decompose organic matter, and increase microbial activity in the soil. They are, therefore, very useful in a soil ecosystem, keeping the soil fertile through their activities.

They are very easily recognized by their slender elongated bodies and legs. Their legs, especially, are quite long. Although they are found worldwide, their diversity is greatest in the tropics. Easily attracted to light, you can see them clinging to the walls with their long legs spread out. Or if you are out for a walk in the morning, they can be seen resting on leaves. Interestingly, crane flies can often be seen walking as easily as flying!

Flies in Science Classrooms

The housefly, no doubt, will continue to be the one that students will encounter most often in their lessons. Why not make it interesting to teach a lesson on the mouth parts of a fly in a different way? Mouth parts are for feeding, and what better way to learn about them than to actually see a fly feeding.

How does one do this? To begin with, one would, of course, need a live fly. And, manipulating a small fly can be a tricky affair! But with a little bit of practice, you should be fine! It's only fair to mention that this investigation calls for a lot of patience and time, but is well worth the time spent in doing it, for I assure you that a lot more than how a fly detects or feeds is learnt through such activities. For example, this investigation will show that flies taste with their feet!

Leave some overripe banana or a mango around, and very soon you will see many houseflies paying them a visit. Use a small tea strainer or a moist cloth to trap a few of these flies, and store them inside a dry transparent jar. Do not keep too many of them inside one jar.

The next few steps are the tricky ones. Take three glass slides, and number them 1, 2 and 3. Put a few drops of water on 1 and, 2, and sugar solution on 3.

The step following this has to be done very quickly. Smear some Fevicol (not Feviquick, please note) on your fore finger, open the jar with the trapped flies, and touch the thorax of the nearest fly with your forefinger. The fly will get stuck to your finger. Hold it gently with your fingers in such a way that both its wings remain folded on its back. Don't worry - at the end of this experiment, you can release the fly by washing your forefinger in water. The fly will be wet for some time (you can gently dab it dry with a cloth), but will soon dry itself out, and fly.

The fly will be stressed because of its captivity. When you gently lower it close to the water-drop on slide 1, you can actually see its proboscis pop out of its head to drink water. When it has finished drinking water, take it off from slide one, and now lower it onto the water drop in slide two in such a way that its feet touch the water. Do you see the proboscis coming down?

Now, repeat the same with slide three, and you will see that as soon as its legs touch the sugar solution, out pops the fly's proboscis to feed on the sugar solution. You may now try different kinds of food, and investigate the fly's feeding preferences or how much it needs to feed on, etc. Seeing an insect feed creates an active learning atmosphere in the classroom, which can then be followed up with anatomical details under the microscope.

Conclusion

This is but a small introduction to a few families of flies that may be found more commonly in our human environments, and are big enough to be recognised. More than 1,60,000 species of flies, and still counting - makes me agree with Nash, when he says:

> God in his wisdom
> Made the fly
> And then forgot
> To tell us why
>
> –Ogden Nash

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THE SUCCESS OF COSTA RICA

Shruthi Rao

Generating energy from eco-friendly renewable resources has become an imperative for the long-term sustenance of our planet. How did Costa Rica, a small Central American nation become the first to achieve 100% energy production from renewable sources? What are the advantages and disadvantages of different kinds of energy sources? This article examines Costa Rica's achievement in the context of the current energy scenario in the world and also explores factors that might aid or hinder the development of renewable energy resources.

Introduction

Media reports are full of depressing news about the state of the earth. Headlines warn us about global warming. News analysts alert us to depleting global reserves of fossil fuels. Websites publish lists of the top 10 polluted countries in the world. Environmental magazines carry articles about how the Earth is being pumped full of toxins. These reports, unfortunately, are quite true.

One of the main reasons that has contributed to the Earth reaching this state, is the growing energy needs of human beings. The energy we currently rely upon is produced mainly by burning up fossil fuels. Fossil fuels are non-renewable (and therefore exhaustible); also, burning them causes pollution. The solution to our energy needs lies in harnessing renewable energy--the kind of energy that is constantly and naturally replenished, and doesn't pollute, the way fossil fuels do.

With the knowledge that this kind of clean and green energy is essential to a secure future, a growing number of countries are trying to reduce their dependence on traditional sources of energy and invest in the development of renewable energy sources.

But can renewable energy technology become widespread? Is it feasible? Can we dare to hope that one day in the future, the earth will be largely powered by renewable sources of energy?

Costa Rica shows us the way

Part of the answer arrived in the month of March of 2015, in the form of a cheerful piece of news, from the country of Costa Rica, in Central America. Costa Rica became the first country in the world to run on 100 percent renewable energy, i.e. Costa Rica has fuelled 100 percent of the energy requirements for the entire country, for 75 continuous days this year, by using only renewable sources of energy.

But why exactly is this piece of news so remarkable? To understand this, let's first take a quick look at the energy situation in the world.

The energy needs of the world

Nearly 70 percent of the total energy produced in the world is from fossil fuels--coal, oil and natural gas. Nuclear energy, which is the energy

generated when atoms are fused or split, constitutes about 11 percent of the total energy in the world. Though it does look like a clean and efficient way to produce energy, disposing of hazardous nuclear waste is a major problem. Besides, there can be disastrous consequences in case something goes wrong with a nuclear plant.

On the other hand, renewable sources of energy are safer, relatively less non-polluting, and are not exhaustible. In hydroelectric power, for instance, electricity is produced by making use of the gravitational force of water falling or flowing. The force of the water operates a turbine, which turns a generator to produce electricity. Though it is a form of clean energy, it comes with its own problems. It involves building large dams, and so requires vast tracts of land, resulting in communities being displaced. Today, 15 percent of the earth's energy needs are fulfilled by hydroelectric power.

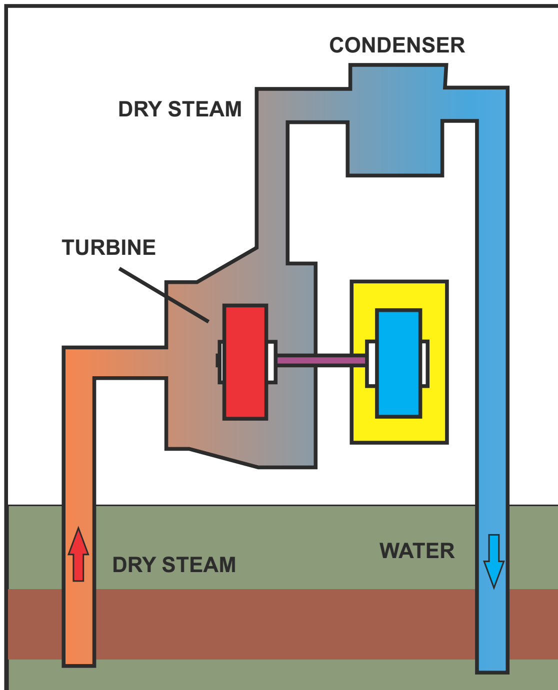
Less than 5 percent of the total energy being produced in the world now comes from solar, wind, biomass, and geothermal energy. In our efforts to sustain human life on the planet, these are the sources of energy that we need to tap into extensively.

Of these, solar energy is the most abundant source of energy on Earth. In fact, the amount of solar energy that falls on Earth in one hour is enough to fuel the energy needs of the entire planet for more than a year! But converting solar energy into electricity involves the use of photovoltaic panels, which are still quite expensive.

Solar Powerstation in Hong Kong

Source: https://en.wikipedia.org/wiki/Solar_power

Wind energy is another abundant resource, where a wind turbine powered by the wind, produces electricity. Biomass energy, where biomass or materials of plant origin is used to produce energy, is also widely used. It is the earliest form of energy to be used by humans. Geothermal power plants use underground steam to move turbines, and produce electricity. There are several other ways to produce energy, for example, those that make use of ocean tides and waves.



Geothermal Power Plant

But you can see the picture--renewable energy sources are a very small fraction of the total energy mix in the world.

The scenario is not that different in India. Today, 60 percent of India's energy is produced by fossil fuels, 16 percent from hydroelectricity, and only about 13 percent from other renewable sources of energy.

The Costa Rica story

Now that we've seen these numbers, let's come back to Costa Rica. Nearly 80 percent of the energy requirements of Costa Rica are fulfilled by hydroelectric energy, about 16 percent by wind, geothermal and other clean energies. Only about 4 percent is through fossil fuels. The contrast with elsewhere in the world is quite remarkable.

In those 75 days in which the country was fuelled completely by renewable sources of energy, Costa Rica didn't have to use the 4 percent energy from fossil fuels at all. Hydroelectric energy made up for it, hence achieving 100 percent renewable energy.

But is it easy for other countries to achieve this milestone?

There are some things that we must keep in mind in the context of Costa Rica's achievement. The fact that this 100 percent was achieved was mainly because during this time, there was abundant rainfall in the catchment areas of the four large hydroelectric stations in the country.

Besides, Costa Rica is a small country, the size of Punjab. Its population is less than even the population of Tripura. This country is mainly involved in tourism and agriculture, and doesn't have energy-intensive industries. And, Costa Rica is fortunate in terms of location - it is situated in an area with an abundance of two renewable sources - both hydropower and geothermal energy.

That should not take away credit from Costa Rica's achievement. Their determination to achieve this milestone is commendable. For a long time, Costa Rica has been a fore-runner among countries that have efficiently utilised renewable energy. This is due mainly to The Costa Rican Electricity Institute (ICE), which has been noted for its efficiency, foresight, and its stress on environmental sustainability. Costa Rica also has the ambitious aim of becoming a carbon neutral country by 2021, i.e. it intends to keep its carbon emissions to zero. This achievement has gone a considerable way in fulfilling that goal.

Costa Rica has its share of problems too

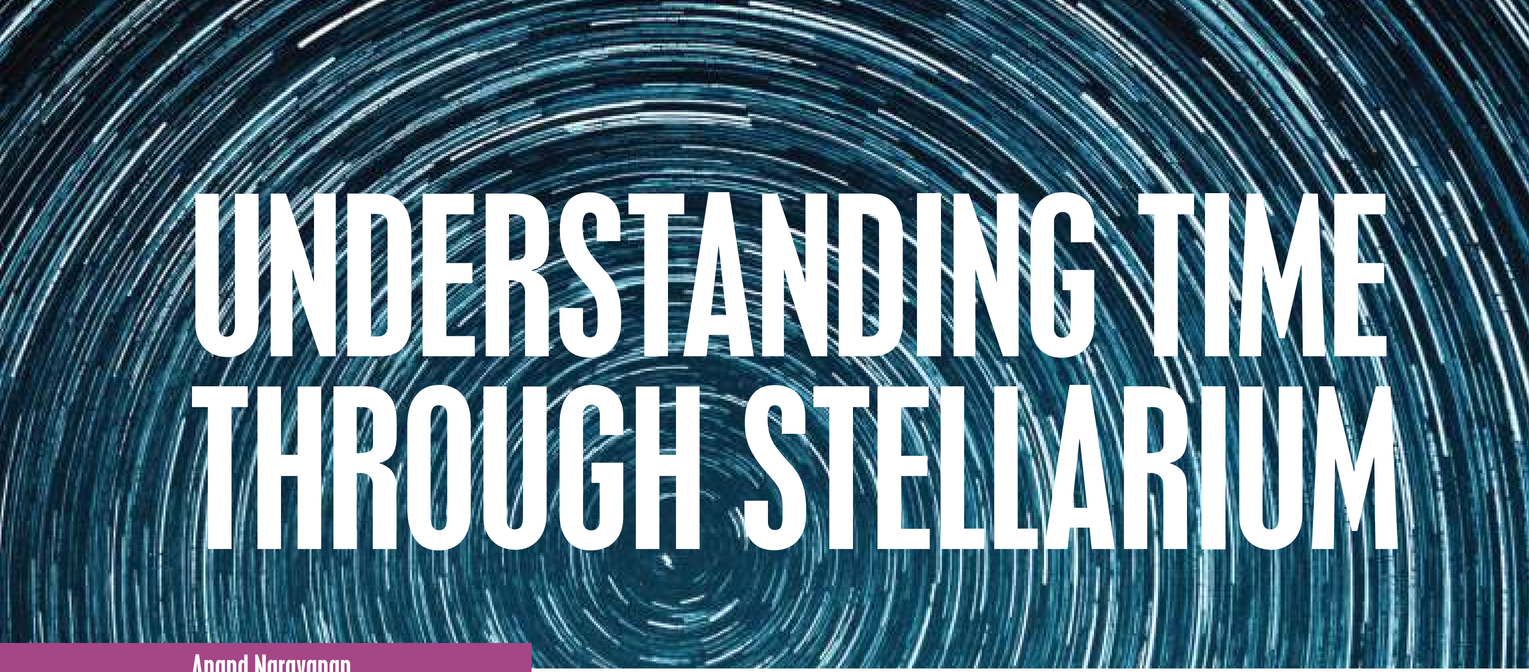
There are some problems with maintaining Costa Rica's impressive record. Hydroelectric power is a major part of the energy mix in Costa Rica. It is not practical to depend solely on this, since hydroelectric power is dependent on the weather. In summer, if there are water shortages, the country will have to fall back on fossil fuels. In fact, this was exactly the case in the drought of 2014 that resulted in a lack of drinking water, and caused damage to crops and livestock.
During this period, diesel generators had to be pressed into service to fulfil the country's energy requirements.

The most exciting alternative is another source of energy that Costa Rica has in abundance--volcanic geothermal energy, which is continuously generated, and does not depend on weather conditions. But potential locations for geothermal plants are inside Costa Rica's national parks. Building geothermal plants will entail building roads, and drilling to reach underground resources. So, the country will have to make a choice between utilising geothermal energy and protecting national parks. Also, conservationists have argued that the country has not sufficiently explored the possibilities of wind energy to justify building geothermal plants inside national parks.

Conclusion

In spite of these problems, it cannot be denied that Costa Rica's achievement is a big step ahead. One hopes that it will serve as an inspiration to other countries, and spur them to step up their own renewable energy efforts, towards the ultimate aim of creating a greener planet.

__Shruthi Rao__ is a writer based in Fremont, USA. She has an M.Tech in Energy Engineering. Her short fiction has won several awards, and her articles on science, travel and lifestyle appear regularly in renowned publications.



UNDERSTANDING TIME THROUGH STELLARIUM

Anand Narayanan

Does the Sun rise from and set at the same position every day? What does its rising and setting position have to do with the length of our days and nights? If we were to pick one of the stars we see in the night sky, and look at it every day, for a year, would it look like it never moved? How do we introduce young students to such mysteries of space and time, inside the four walls of our classroom? This article explores the use of Stellarium, a free open source software, as a teaching aid that can engage teachers and students alike, helping them visualise some astronomical phenomena, and understand concepts related to them, in a less abstract and more engaging way.

A great deal of our concept of time has come from observing the motion of heavenly bodies. The systematic way in which the Sun, the Moon, planets and stars travel across the sky, forms the basis on which days, nights, months and years are defined. The time of the day comes from the position of the Sun in the sky. The month is based on the revolution of the Moon around Earth. The year and seasons are linked to the apparent annual motion of the Sun, as seen from Earth.

In this age of digital clocks, the sky may have turned obsolete as a means to know time. But, there is still a great deal of merit in learning concepts fundamental to celestial time keeping. How well do we know answers to seemingly simple questions like where exactly does the Sun rise; is the duration of the day the same as the duration of the night; does the position of the Sun in the sky change with geographic location? Finding out answers to such questions through real world observations consume a lot of time, and are not practical at all times. Planetarium softwares can be a great substitute to real world observations.

There are several softwares that help one visualize the apparent movement of objects in the sky. STELLARIUM is one such open-source software obtainable free of cost. STELLARIUM can be downloaded from www.stellarium.org

STELLARIUM displays objects in the sky for any given date and time from a location of our choice on Earth. This software has many useful features. One can move forwards and backwards in time, zoom-away or zoom-into an object, remove Earth's atmosphere, change our location of observation, switch on the labels and boundaries for constellations, include deep-sky objects like galaxies, star clusters and many more. These features are easy to locate on the software, and are also well explained in the user's guide that comes along with the software.

This article describes a few exercises which can engage students in learning about the patterns and periods of the sky.

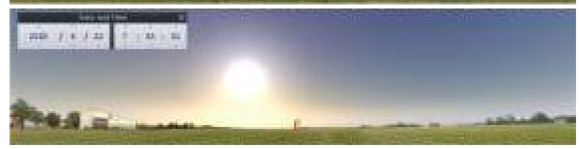
The rising & setting position of the Sun

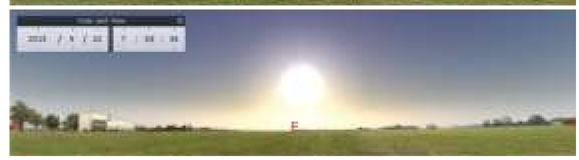
We all know that the Sun seems to rise in the East and set in the West, when seen from Earth. But is this always true? Does the Sun always rise exactly due East and does it set exactly due West?

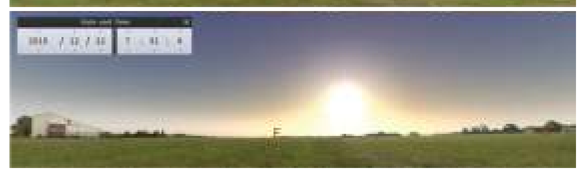
It is easy to investigate such questions with STELLARIUM. Here is a sequence of steps that may help with answers.

1. In STELLARIUM, change your viewing orientation so that you are facing EAST.
2. Set date to March 1st and time to 7:30 am (the year does not matter). You will see that the Sun has risen NOT exactly in the East, but a bit South of East (as shown in the image below)

3. Keeping the time fixed (7:30 AM), keep incrementing the date from March 1st in steps of one day. Notice how the rising position of the Sun changes.
4. You will notice that the position of the Sun drifts in the following manner
    - March 21 (± 1 day) the Sun rises exactly due east
    - From March – June, the rising Sun keeps drifting towards North of East.
    - June 21 (± 1 day), the Sun reaches maximum elongation North of East.
    - From June – September, the rising Sun starts drifting towards South.
    - September 22 (± 1 day), the Sun again rises exactly due East







- From September – December, Sun drifts towards South of East
- December 22 (± 1 day), the Sun reaches its maximum elongation South of East, and the cycle repeats.

Some facts to learn from the above exercise:

1. The Sun does not always rise exactly from the East
2. Neither does it always set exactly at the West.
3. The Sun rises exactly due east only twice a year. These two days are called vernal equinox or *Vasantha Sampath* (March 21st ± 1 day) and Autumnal Equinox or *Sharat Sampath* (September 22nd ± 1 day). “Equinox” loosely translates into “equal day and night”.
4. In the calendar system that came about in India centuries ago, the year is divided into two halves. The 6 month duration from December – June, when the rising (and setting) position of the Sun moves from South to North, is called *Uttarayana* (it means northward journey, *ayana*: journey, *uttara*: north). The other six months of duration from June – December,

The rising & setting of stars

Like the Sun, stars also seem to rise in the East and set in the West. This is because of the Earth’s spin oriented from West to East. In STELLARIUM, by increasing the time speed from the bottom control panel one can observe the apparent movement of stars in the sky, fast-forwarded in time.

when the rising (and setting) position of the Sun drifts from North to South, is called *Dakshinayana* (the journey southward).

5. Do these observations hold true if we are located somewhere in the southern hemisphere? This can be investigated by choosing a southern hemisphere location from the “Location Window” (e.g. Kuala Lumpur, Malaysia)

The duration of day & night

The rising and setting time of the Sun governs the duration of day and night. Curiously, day and night are not always of the same duration. Depending on the month of the year, a day could be longer or shorter than the night. The difference also depends on our geographic location. These concepts can be explored through STELLARIUM. For clarity, it is good to do this exercise for three different geographic locations.

From a location close to the equator

1. Choose an observing location close to the equator of Earth (e.g. Chennai)
2. Starting from the month of January, proceed in steps of one month.
3. For each month, note down the time of the day when the Sun rises from the Eastern horizon. Try to make a simple table of your recordings. Is there any trend to the rising time of the Sun over a one year time period?
4. Once you complete the above process, change your orientation towards the West
5. For January through December, note down the time when the Sun goes below the Western horizon. Again, tabulate your recordings.

Is there any trend to when the Sun sets?

From the two tables, calculate the duration of daylight / night across the year. Is there any trend in the duration of daylight compared to the duration of night for the uttarayana and dakshinayana halves of a year?

From a location away from the equator

1. Choose an observing location away from the equator (e.g. Srinagar)
2. Repeat the above procedure

From the table of values, calculate the duration of day / night. Is there any trend in the duration of daylight compared to the duration of night for the uttarayana and dakshinayana halves of a year? How does this compare with the location closer to the equator?

From the north pole

1. Choose your observing location as North Pole (latitude 90 deg North of the equator)
2. Repeat the above procedure.

What is peculiar about the day and night cycle at the North Pole? Does this explain why the North Pole is not habitable?

The rising & setting of stars

Like the Sun, stars also seem to rise in the East and set in the West. This is because of the Earth’s spin oriented from West to East. In STELLARIUM, by increasing the time speed from the bottom control panel one can observe the apparent movement of stars in the sky, fast-forwarded in time.

From the soutern hemisphere

1. Choose a location close to and below the equator in the southern hemisphere (e.g. some place in Sri Lanka) and repeat the above steps.
2. Choose a location away from the equator in the southern hemisphere (e.g. Kuala Lumpur, Malaysia) and repeat the above steps.
3. Choose the South Pole and repeat the above steps.

Is there any difference in the duration of days and nights with a change in months, for those living in the southern hemisphere? Are the uttarayana and dakshniyana halves of a calendar year the same as what is seen from the Northern hemisphere?

The rising & setting of stars

Like the Sun, stars also seem to rise in the East and set in the West. This is because of the Earth’s spin oriented from West to East. In STELLARIUM, by increasing the time speed from

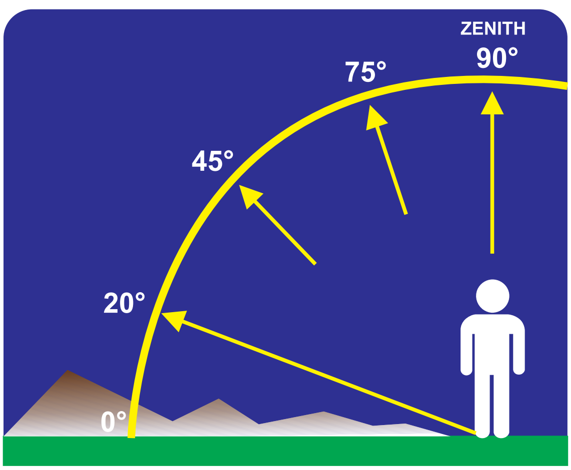
the bottom control panel one can observe the apparent movement of stars in the sky, fast-forwarded in time.

The duration of a day and night cycle is based on how long it takes for celestial objects to return to their starting position. Interestingly, this duration of day-night is different if we choose a nearby object like the Sun as our reference, as opposed to the more distant stars.

This can be investigated with the following exercise, which requires some careful manipulation of the software.

For this exercise, the students would need to know two concepts:

(a) What "altitude" means.



(b) How angles are subdivided into minutes and seconds?

Altitude is a measure of how high or how low an object is with reference to our horizon. A star that is just rising from the Eastern horizon has an altitude of 0 degrees. A star that is setting at West also has an altitude of 0 degrees. A star that is directly above our head (called the zenith point) is at an altitude of 90 degrees. A star that has crossed the zenith has an altitude less than 90 degrees. The following figure illustrates the definition of the altitude angle.

Just as one hour is divided into sixty minutes, and a minute further into sixty seconds, angles that span less than a degree are divided into minutes and seconds. 1 minute is 1/60th of a degree, and one second is 1/60th of a minute. Instead of writing angles in decimal notation, it is common to express them in minutes and seconds. Thus

45.5 degrees is also written as 45 deg 30 minutes

60.73 degrees is also written as 60 deg 43 minutes and 48 seconds

Having understood the two concepts, one can proceed with the following exercise that will help one understand the definition of a day.

The daily period of the Sun

1. Select your observing location.

2. Pick any time (say 10:00 am) and a date of choice.

3. Pause time through the controls on the bottom panel. This step is very important, otherwise you may have difficulty carrying out the necessary observations.

4. Click on the image of the Sun on screen. STELLARIUM will display, among a host of other things, the altitude of Sun for that time.

5. Increase the time in steps of hours and find out how much time it takes for the Sun to return to the same altitude in the sky.

6. You will notice that the altitude of the Sun comes back to the starting value in approximately 24 hours. (There will be a small difference of a few arc minutes in angle. An arc minute is 1/60th of a degree and is a tiny measure of angle. This difference can therefore be ignored for the purpose of our exercise here)

Thus, our current definition of a day-night cycle of 24 hours is based on the apparent daily motion of the Sun in the sky. 24 hours is the time it takes for the Sun to complete a full circle around Earth. (We perceive this relative motion coming from the rotation of Earth. The Sun does not go around Earth). 24 hours is the duration of a **solar day**, and this time system is called **solar time** or **civil time.**

The daily period of stars

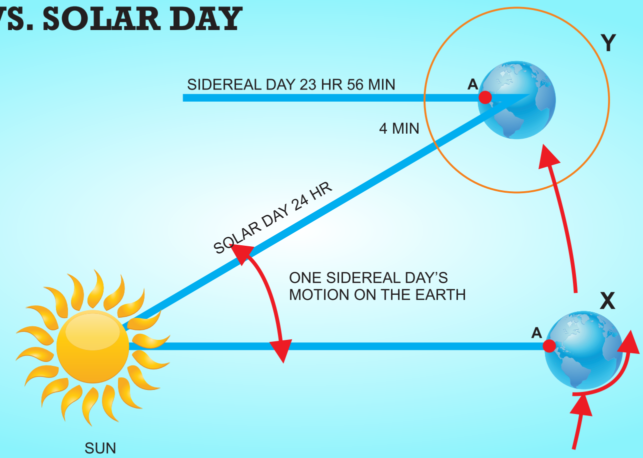
Following the same steps as above, instead of picking the Sun, select a star (any star) visible at night.

1. Click on the image of the star. STELLARIUM will display the altitude of the star.

2. Increase the time in steps of hours and find out how long it takes for the star to return to the same altitude in the sky.

3. You will find that it takes not 24 hours, but only 23 hours and 56 minutes for the star to return

SIDEREAL DAY VS. SOLAR DAY



to the same position in the sky. In 24 hours, the star advances an extra 1 degree in altitude.

Thus, if instead of the Sun, we were to use any other star in the sky as the basis for our definition of a day-night cycle, the duration would be less than 24 hours. To be precise, the day-night cycle would be 23 hours and 56 minutes. This scheme of definition of a day-night cycle is called the **sidereal time.** "Sidereal" is a word with Latin roots and it means "in relation to the stars".

Since our everyday activities are so tightly linked to the rising and setting of the Sun, all the clocks that we use for our daily purposes are based on the solar day of 24 hours. Astronomers, in contrast, use sidereal time often because of their interest in objects beyond the Sun, which become accessible during the night.

The solar day is longer than the sidereal day because of Earth's revolution around the Sun.

The above illustration shows Earth spinning along its imaginary axis and at the same time orbiting the Sun. Imagine that point A on Earth corresponds to an observer's location. One needs a reference point in the sky against which the spin of the Earth can be measured. For example, how would one know whether Earth has completed a 360 degree rotation on its axis? Only if there is a reference point outside of the Earth, one can talk about the Earth's spin relative to it. This reference point can be the Sun, or more distant stars. This choice distinguishes the solar day from the sidereal day.

The time it takes for point A on Earth to spin 360 degrees with reference to distant stars is 23 hours and 56 minutes. During this time, stars return to their positions in the sky. But in that same time, the Earth moves ahead in its orbit around the Sun. By how much does the Earth move in one day?

The Earth takes 365 days to complete one full revolution of 360 degrees around the Sun. Thus, in one day Earth moves by approximately 1 degree in its orbit. This suggests that the Earth has to spin an extra 1 degree for the Sun to return to its prior position in the sky. To spin an extra 1 degree, Earth takes about 4 minutes, which explains the offset of 4 minutes between sidereal and solar days.

Conclusion

These are only a handful from the many exercises one can carry out using STELLARIUM. The software is highly resourceful. Its user's guide is a good reference in case you need help in navigating through the software. Many universities have created laboratory exercises using STELLARIUM. These can be accessed by searching the internet. As you become familiar with STELLARIUM's interactive features, you will be able to write your own exercises to explore further, the patterns and movements of the changing sky.

Anand Narayanan *teaches astrophysics at the Indian Institute of Space Science & Technology. His research is on understanding how baryonic matter is distributed outside of galaxies at large scales. He regularly contributes to astronomy educational and public outreach activities. Ever so often he likes to travel exploring the cultural history of south India.*

i wonder...

Write for Us.

I wonder... is a magazine centred on middle-school science education. Each issue of this biannual magazine (November, May) will be originally published in English, and later translated into Hindi and Kannada. It will also be available in multiple formats – online and print.

We are always on the look-out for articles that build on middle school science concepts. So, if you have an idea for an article with the potential to provide a wider or deeper understanding of any topic in science that is dealt with in the middle school curriculum, do share it with us. Your article could explore the history of a concept, its applications, or its inter-linkages with other concepts taught across different science streams. For more specific information on the broad themes on which we look for articles, do check out the various sections in this issue of our magazine. Or get in touch with us – we will help you decide which section your article would match best.

We particularly welcome submissions from middle-school science teachers and teacher educators. We'd like to read more of your experiences with teaching science, and activities that you have tried and tested in your classrooms to improve learning outcomes. Do also tell us your impressions of the articles in each of our issues. If selected, your feedback will be featured in our Mail Bag in the next issue of our magazine. We accept submissions throughout the year. Do remember, though, that if you'd like to see your article published in the May 2016 issue of our magazine, your ideas must reach us latest by the 30th of January, 2016. So, hurry - please send a brief outline of your idea (not exceeding 500 words) to iwonder.editor@azimpremjifoundation.org, with your name and a brief bio. We'll get in touch with you as soon as possible.

The Editors.

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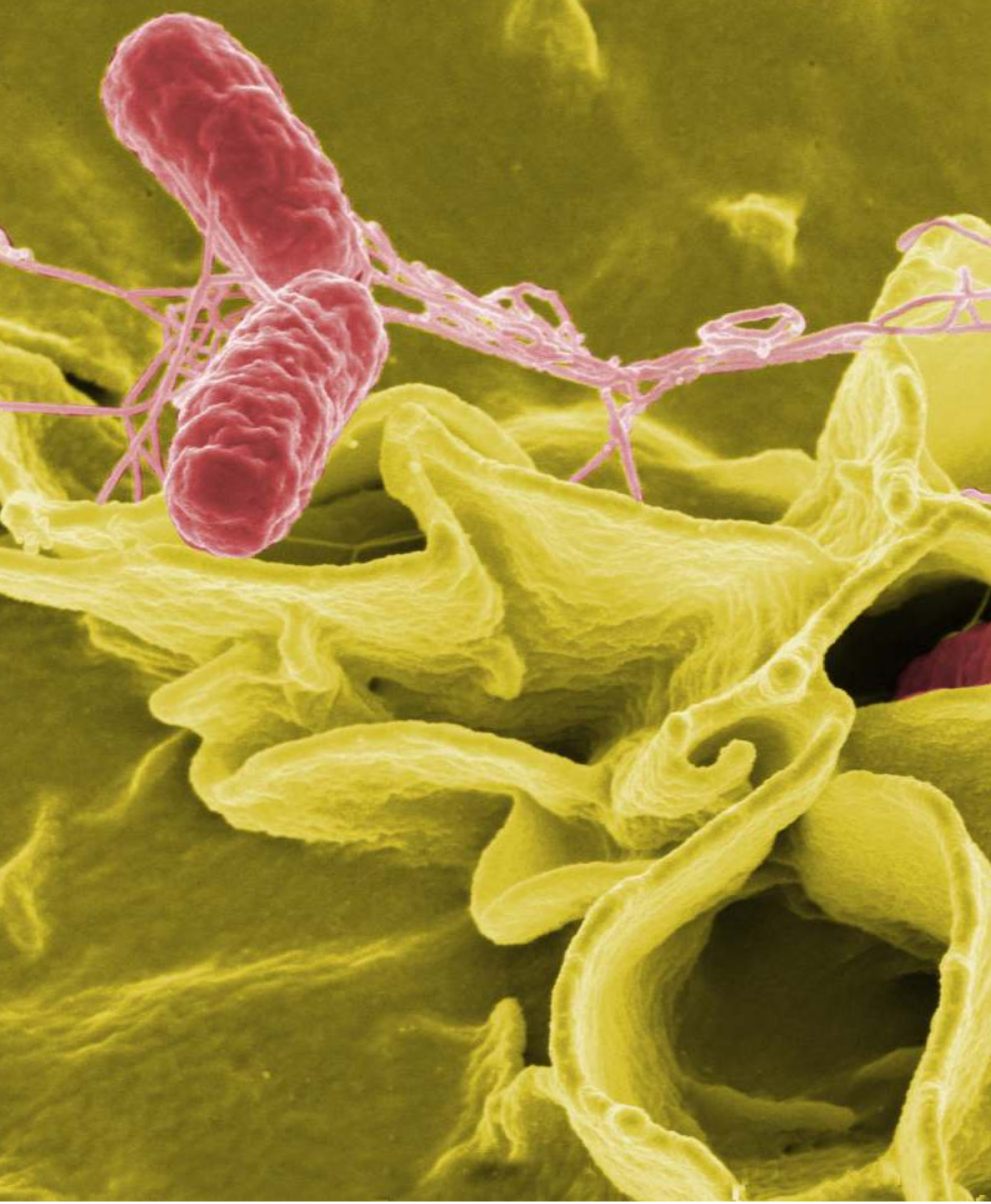


'Intricate Interactions of a cellular kind. View under a Scanning Electron Microscope'.
Catch the next issue of *I wonder* for an exciting foray into the world of **Interactions** and a special feature on **Emerging Trends in Biology**!

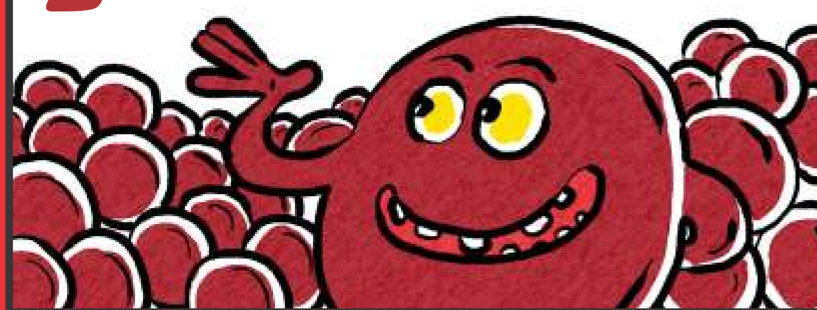
TEN THINGS YOU DIDN'T KNOW ABOUT

Srikanth K.S

1 NEARLY 7% OF THE WEIGHT OF YOUR BODY IS MADE UP BY BLOOD!

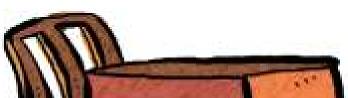
AN AVERAGE WOMAN HAS ABOUT 4.5 LITRES OF BLOOD IN HER BODY, WHILE AN AVERAGE MAN HAS ABOUT 5.6 LITRES. INTERESTINGLY, PEOPLE WHO LIVE AT HIGH ALTITUDES (IN THE MOUNTAINS) CAN HAVE UP TO 2 LITRES OF EXTRA BLOOD COMPARED TO THOSE WHO LIVE AT LOWER ALTITUDES. THIS IS BECAUSE THE AIR AT HIGH ALTITUDES HAS LESS OXYGEN, SO PEOPLE LIVING THERE NEED EXTRA BLOOD TO DELIVER THE REQUIRED AMOUNT OF OXYGEN TO THEIR LUNGS.

2 THERE ARE ABOUT ONE BILLION RED BLOOD CELLS IN TWO TO THREE DROPS OF BLOOD!



3 EACH RED BLOOD CELL LIVES IN YOUR BODY FOR AROUND 120 DAYS.

ABOUT 2 MILLION BLOOD CELLS IN YOUR BODY DIE EVERY SECOND! BUT DON'T WORRY – NEW ONES ARE BEING MADE ALL THE TIME TO REPLACE THE ONES THAT DIE! IN FACT, WHEN YOU DONATE BLOOD, THE RED BLOOD CELLS YOU LOSE ARE REPLENISHED WITHIN 3 TO 4 WEEKS.



4 THERE ARE FOUR MAIN TYPES OF BLOOD GROUPS IN HUMANS (A, B, AB AND O).

DOGS ALSO HAVE FOUR TYPES, WHILE CATS HAVE AT LEAST 3 TYPES. BUT THE CLEAR WINNERS ARE COWS, WITH MORE THAN 800 TYPES!

5 IF ALL OF THE ARTERIES, CAPILLARIES AND VEINS IN AN ADULT HUMAN WERE LAID OUT END-TO-END IN A LINE, THE LINE WOULD STRETCH TO A DISTANCE OF ABOUT 1,00,000 KILOMETERS.

SINCE THE CIRCUMFERENCE OF THE EARTH IS ABOUT 40,000 KM, A PERSON'S BLOOD VESSELS CAN BE WRAPPED AROUND THE EARTH APPROXIMATELY 2.5 TIMES!

6 A BLOOD CELL CAN DO A COMPLETE LAP OF YOUR BODY IN LESS THAN A MINUTE. THAT IS FAST!

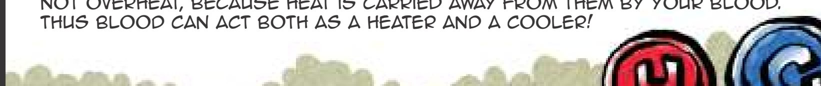
7 THE SIZE OF THE BODY IS INVERSELY RELATED TO THE RATE AT WHICH THE HEART BEATS – THE BIGGER THE ANIMAL, THE SLOWER IS ITS HEART RATE.

AN ADULT HUMAN HAS AN AVERAGE NORMAL HEART RATE OF ABOUT 70-75 BEATS PER MINUTE. THE LARGEST ANIMAL IN THE WORLD, THE BLUE WHALE (WITH A HEART THE SIZE OF A MINI CAR) HAS A HEART RATE OF ONLY 5 BEATS PER MINUTE. ONE OF THE SMALLEST MAMMALS, THE SHREW, HAS A HEART RATE OF ABOUT 1,000 BEATS PER MINUTE!

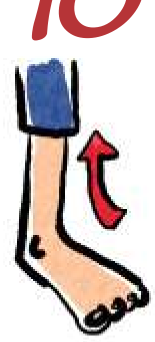
8 YOUR HEARTBEAT (WHICH DOCTORS LISTEN TO USING A STETHOSCOPE) IS ACTUALLY THE SOUND OF HEART VALVES (PRESENT BETWEEN DIFFERENT CHAMBERS IN THE HEART) OPENING AND CLOSING AS THEY PUSH BLOOD FROM ONE CHAMBER TO ANOTHER.

9 WE ALL KNOW THAT BLOOD CARRIES OXYGEN FROM LUNGS TO TISSUES AND CARBON DIOXIDE FROM THE TISSUES TO THE LUNGS. IT ALSO CARRIES NUTRIENTS AND HORMONES TO VARIOUS PARTS OF THE BODY AND WASTE PRODUCTS FROM THESE PARTS TO THE KIDNEYS AND LIVER TO BE EXCRETED.

IN ADDITION TO ALL OF THESE, BLOOD CARRIES ONE OTHER IMPORTANT THING – HEAT. THE EXTREME PARTS OF YOUR BODY (SUCH AS FINGERS AND TOES) STAY WARM BECAUSE HEAT CREATED IN THE CENTRE OF THE BODY (FOR EXAMPLE IN THE MUSCLES) IS CARRIED TO THEM BY YOUR BLOOD. ON THE OTHER HAND, BODY PARTS LIKE THE LIVER, HEART, MUSCLES AND BRAIN DO NOT OVERHEAT, BECAUSE HEAT IS CARRIED AWAY FROM THEM BY YOUR BLOOD. THUS BLOOD CAN ACT BOTH AS A HEATER AND A COOLER!



10 ON EARTH, BECAUSE OF GRAVITY, A PERSON'S BLOOD USUALLY POOLS IN THE LEGS. LEG VEINS HAVE VALVES THAT HELP THE BLOOD FLOW FROM THE LEGS BACK TO THE HEART. BUT WHEN THERE IS NO GRAVITY, LIKE IN SPACE OR ON THE MOON, BLOOD POOLS IN THE CHEST AND HEAD AND CAUSES ASTRONAUTS TO HAVE STUFFY NOSES, HEADACHES AND PUFFY FACES. IF AN ASTRONAUT STAYS IN SPACE LONG ENOUGH, HIS/HER HEART WOULD ENLARGE SO THAT IT CAN HANDLE THE INCREASED BLOOD FLOW IN THE AREA SURROUNDING IT.



Srikanth K.S is an independent research consultant. He has a doctorate in immunology, and his primary area of interest is in host-pathogen interactions. He can be contacted at sriikis@gmail.com

ACTIVITIES

Alan Lightman is a well- known physicist and writer. In an essay in his book 'Dance for Two', he says that most people don't do experiments to see for themselves; they just accept what they have read. I think this is true. Nowadays, we feel that watching an experiment on the internet is the same as doing it. I am outlining some simple experiments here. These can be used in science classrooms to reveal the properties of water. How many of these have you read about, and how many have you done?

1 WATER IS A POLAR MOLECULE

For the most elegant and simple way to see this, you need a tap, a balloon and a piece of nylon or tereylene cloth. Blow up the balloon, open the tap to let out a thin stream of water. Rub the balloon vigorously with cloth and then hold it to the stream. To observe the behavior of a non-polar liquid, you will need to get a $50cm^3$ disposable syringe, some kerosene or petrol and a partner. Have your partner fill the syringe with petrol and allow it to fall into a container in a steady stream. Repeat the experiment with the charged balloon, and see the difference.

2 ICE IS LESS DENSE THAN WATER

This we see all the time in our iced drinks. It seems normal. To compare, take two glass jars; in one put water and drop in an ice cube. In the other, take molten wax (easy to melt candles on the gas stove) and add a piece of candle to it. Observe.

3 WATER HAS HIGH SURFACE TENSION

This arises because of hydrogen bonding between the water molecules. Again comparison helps. Take two rimless drinking glasses. Stand them on a level surface and fill them to the brim, one with water and the other with petrol. It would be good to stand the glasses in a tray to catch any spills. Using a dropper add extra drops of each of these liquids on to its respective glass. How many drops can you add to the water glass and what does it look like? How many to the petrol glass and what does it look like?

Take two pins, put them on separate pieces of newspaper and float them on the liquid surfaces. Wait and observe.

4 WATER EXPANDS ON FREEZING

Fill a water bottle to the brim with water, screw on the cap tightly and leave in the freezer till it freezes fully. It might be less messy if you put the bottle in a plastic bag before putting it in the freezer.

5 THE DENSITY OF WATER IS THE HIGHEST AT ABOUT 4°C

This fact is used to explain why ponds freeze from the top. If you put in a vessel full of water in the freezer you can observe that ice forms from the top. Using a glass jar, food colouring, a thermometer and the fact that liquids of different densities don't mix easily, can you design an activity to show that water at 4°C is the densest form of this liquid?

i wonder... Azim Premji University